COMBAT RATION NETWORK
FOR
TECHNOLOGY IMPLEMENTATION

Final Technical Report STP#2027

"Quality Improvement Project for Shelf Stable Bakery Products"

Results and Accomplishments (February 2007 – June 2009)

Report No: FTR 217

CDRL Sequence: A003

July 2009

CORANET CONTRACT NO. SPO103-02-D-0024

Sponsored by:

DEFENSE LOGISTICS AGENCY

8725 John J. Kingman Rd.

Fort Belvoir, VA 22060-6221

Contractor:

THE CENTER FOR ADVANCED FOOD TECHNOLOGY

The School of Environmental and Biological Science

Rutgers, The State University of New Jersey

New Brunswick, New Jersey 08903

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)*	2. REPORT TYPE	3. DATES COVERED *(From - To)*
July 2009	Final	February 2007 - June 2009

4. TITLE AND SUBTITLE

Quality Improvement of Shelf Stable Bakery Products

5a. CONTRACT NUMBER

SP0103-02-D-0024 / 0016

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

5d. PROJECT NUMBER

STP # 2027

5e. TASK NUMBER

5f. WORK UNIT NUMBER

A003

6. AUTHOR(S)

Dr Nesli Sozer
Dr Jozeph Kokini
Mr. Henderikus B. Bruins
Dr William Franke
Ms. Christie Dietzel
Mr Bob Trottier
Ms. Sue Harrington

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

Rutgers, The State University of New Jersey
The Center for Advanced Food Technology
School of Enviromental and Biological Sciences
New Brunswick, NJ 08903

8. PERFORMING ORGANIZATION REPORT NUMBER

FTR 217

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

Defense Logistics Agency
8725 John J. Kingsman Rd
Fort Belvoir, VA 22060-6221

10. SPONSOR/MONITOR'S ACRONYM(S)

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT

Approved for public release; distribution is unlimited.

13. SUPPLEMENTARY NOTES

14. ABSTRACT

Bakery food products are mostly cellular solid food systems which consist mainly of gluten and starch fractions. In bakery food products, the most important quality related problem is staling, which starts right after baking procedure. Staling of food products causes a series of reactions which affect the sensory and physical properties. Retrogradation of starch is the primary mechanism that influences textural properties of cakes. This project created a new Devil's fudge cake formulation by use of gum, modified starch and enzyme technology. Cake samples prepared by combinations of gums, bacterial amylases and pregelatinized starch were found to slow down the starch retrogradation rate. Moisture content, water activity, texture, and X-ray diffractometry graphs were evaluated. The staling rate was found to be accelerated by the fluctuations in temperature from high to low temperatures. Modified starches, enzymes and gums decreased the rate of staling and improved product quality. All Rutgers formulated cakes were found to have 25% less toughness and hardness values as compared to the current product.
Besides cakes, we also studied waffles as a second product. We showed that the staling rate for waffles is faster than for cakes. The

15. SUBJECT TERMS

Ration, Bakery, Shelf Stability, Shelf Life, Cake, Waffles, Staling, Retrogradation

16. SECURITY CLASSIFICATION OF: a. REPORT	b. ABSTRACT	c. THIS PAGE	17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
Unclassified	Unclassified	Unclassified	Unclassified		Henderikus B. Bruins

19b. TELEPHONE NUMBER *(Include area code)*

732-445-6130

IMPROVEMENT OF SHELF LIFE STABILITY OF BAKERY PRODUCTS

Nesli Sözer

Jozef L. Kokini

Rieks Bruins

Christie Dietzel

William Franke

Bob Trottier

Sue Harrington

Center for Advanced Food Technology
Department of Food Science
Rutgers University

TABLE OF CONTENTS

1. ABSTRACT

Bakery food products are mostly cellular solid food systems which consist mainly of gluten and starch fractions. In bakery food products, the most important quality related problem is staling, which starts right after baking procedure. Staling of food products causes a series of reactions which affect the sensory and physical properties. These changes are the main causes of consumer rejection of staled food products. In bakery food products, staling reactions start before microbial deteriorations. As a result, it is the major factor to determine the shelf life. Cakes that are acceptable by the consumer should be moist and soft in texture. Retrogradation of starch is the primary mechanism that influences textural properties of cakes. Currently shelf life of bakery products is extended by control of water activity, moisture and packaging conditions. These preservation techniques lean on the technologies of 1980's. Alternate preservation methods, such as use of ingredients to retard staling mechanism, are crucial.

In this project we aimed to create a new Devil's fudge cake formulation by use of gum, modified starch and enzyme technology. Cake samples prepared by combinations of gums, bacterial amylases and pregelatinized starch were found to slow down the starch retrogradation rate. Moisture content, water activity, texture, and X-ray diffractometry graphs were evaluated. The staling rate was found to be accelerated by the fluctuations in temperature from high to low temperatures. Modified starches, enzymes and gums decreased the rate of staling and improved product quality. All Rutgers formulated cakes were found to have 25% less toughness and hardness values as compared to the current product.

Besides cakes, we also studied waffles as a second product. We showed that the staling rate for waffles is faster than for cakes. The most effective ingredient in controlling the staling rate was the bacterial enzyme. Enzyme containing formulation decreased the toughness values of waffle samples by 50% as compared to control samples.

2. INTRODUCTION

Bread and cake are the products represent the majority of baked goods. Cakes belong to the group of cellular solid foods that have air pockets embedded in a protein and starch network. Baking process consist of three different stages. In the initial stage, batter expansion and moisture loss occurs which is followed by further moisture loss and volume rise reaching to a maximum final stage where air pockets are entrapped inside a food matrix (Megahey et al., 2005). A good quality cake should have high volume with a fine uniform moist crumb. The cake structure can be set by formation of a protein-starch network in circumstances where the expansion of each bubble dominates over destructive events such as coalescence and disproportionation (Pernell et al., 2002). Cakes contain high amounts of sugar, shortening, egg, milk or water together with soft wheat flour. The airy structure of cakes comes from oil/ water emulsion or foam from egg proteins during mixing. Cake quality is strongly dependent on the type of ingredients, formulation and baking conditions. A basic cake production process involves mixing, depositing, baking, cooling and packaging steps (Figure 1).

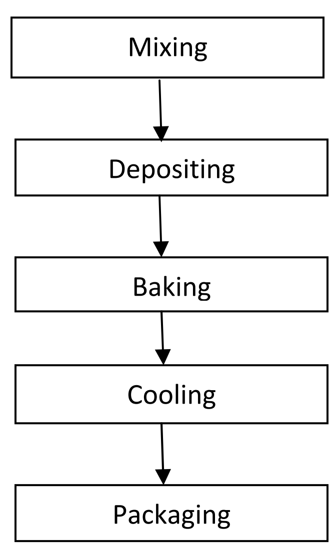


Figure 1. Flow diagram of cake production process

The basic ingredients in a cake batter are flour, fat, egg, milk, sugar and salt. Flour, egg white, milk solids and salt are used to toughen the cake whereas sugar, fat and egg yolk are used to tenderize the cake. Cake batter consists of oil/water emulsion with dry ingredients. The oil part is dispersed in the liquid phase (Painter, 1981).

Foam formation occurs during mixing where air cells are introduced into the batter. The higher the number of air pockets the higher the volume (Handleman, et al.). Starch gelatinization, protein denaturation together with carbondioxide formation gives cake its porous, soft structure. The degree of expansion is dependent on the viscosity of the batter. If the batter is thick, it would be difficult for the air bubbles to escape, which would result in a high volume cake. A low viscosity batter will fail to hold the air cells in the structure resulting in a low volume cake. However, it is so important to achieve the optimum viscosity batter since a high viscosity batter might restricted expansion during baking (Sahi and Alava, 2003, Sumnu and Sahin, 2008) and result in low volume

INGREDIENTS

Fat

Fat has influence on the tenderness and moistness of the cake. Fat entraps air during mixing, which causes discontinuity in the starch and protein network, helping emulsion formation. The use of shortening in the formulation not only improves foam stability but also delays gelatinization by restricting the transportation of water. In the literature it was shown that cakes with margarine in the formulation resulted in low specific gravity batter and higher cake volumes, as compare to cakes with oils, which formed high specific gravity batter and low cake volume (Mizukoshi, 1985; Vali and Choudray, 1990, Sumnu and Sahin, 2008)

Eggs

Eggs help the formation of fine air cells with thin cell walls in cakes. Egg white proteins disperse large volumes of air into the batter during mixing. During the baking process the formed air bubbles expand and protein coagulation will stabilize the structure.

Sugar

Sugar is the second most important ingredient especially in a high ratio cake system. The primary purpose of sugar addition is to provide sweetness to the product. It has also other important functions such as facilitating air inclusion, absorption of water during mixing and limiting available water for protein which would result in a tender cake. High amounts of sugar in the cake recipe will increase the starch gelatinization and egg protein denaturation temperatures, thus improving the loaf volume. Increasing the starch gelatinization temperature provides air bubbles more freedom to expand before the cake structure starts to set (Kim and Setser, 1992; Kim and Walker, 1992). During baking, sugar contributes also to the color and flavor of the cake through browning reactions.

All baked products including cakes are water limited food systems. Starch gelatinization takes place in the presence of water and heat. Excess sugar (55-60%) is reported to shift the gelatinization temperature to higher values. Some researchers claim that sugar limits the available water for gelatinization (D'Appolonia, 1972; Derby et al., 1975) and others believe that it is due to the interaction of sugar with starch chains in the amorphous areas of the starch granule (Spies and Hoseney, 1982).

Flour

Flour is the main ingredient of all baked product formulations. Flour used for bread is high in gluten (wheat protein), but its development is undesirable in cake production. Cake flour should be low in protein content (7-9%), high in starch content with the ability to absorb less water. Figure 2 shows how viscosity of the batter changes within the baking process. In the early stages of baking there is a decrease in viscosity due to melting of shortening and sugar. As soon as the starch in the flour starts to gelatinize, it will cause a gradual increase in viscosity (second stage of baking).

Wheat flour is composed of starch, hemicelluloses and β-glucans. The hemicelluloses and β-glucans improve surface active properties and act as foam stabilizers. Since starch increases the

viscosity of the batter it indirectly helps to inclusion of air during mixing by subdividing the air cells.

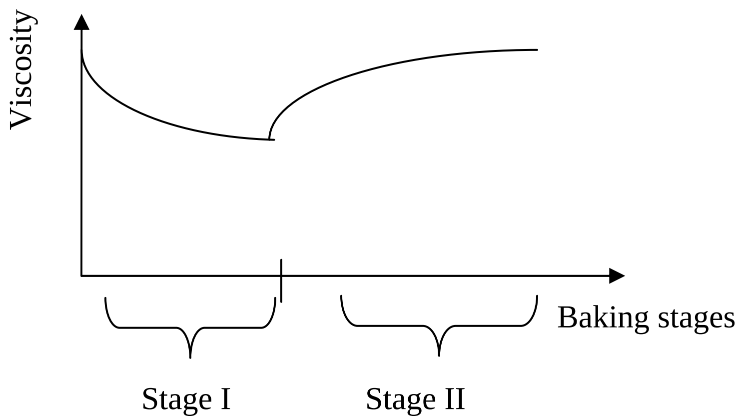


Figure 2. Schematic representation of change in viscosity during baking process

Water

Water is the most important plasticizer in cake batter formulations. It dissolves all the dry ingredients, regulates consistency, and imparts moisture to the final product. It also helps to incorporate air cells in the batter during mixing. These air cells will act as nuclei for the carbondioxide gas produced by the chemical action of baking powder. During cake production a little gluten development is desirable in order to retain the air cell structure. Gluten development takes place in the presence of water. However, the low viscosity of cake batter limits the energy input in the mixing process so that the gluten development is not as much as it is in the bread processing. The gluten network in the cake batter should be sufficient enough to keep the air bubbles trapped, but it should not interfere with the oven rise. The capacity and power of the oven to remove excess water and control the final moisture content and water activity are important criteria that determine not only good textural properties (soft, airy and moist) but also control microbial stability of the final product during storage.

Baking powder

Baking powder is a mixture of baking soda and acid which produces carbondioxide gas through a chemical reaction.

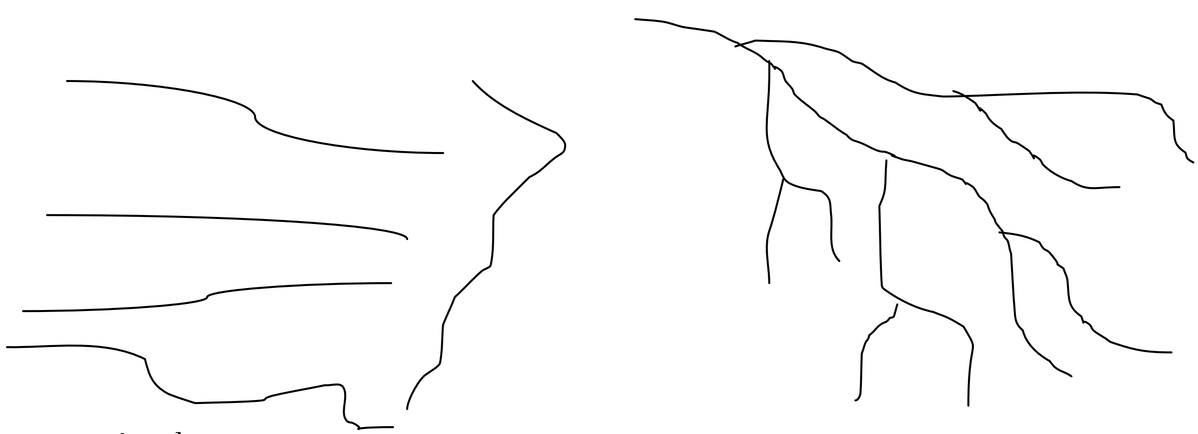
$$\underbrace{NaHCO_3}_{\text{base}} + \underbrace{H^+}_{\text{acid}} \rightarrow Na^+ + CO_2 + H_2O$$

Compared to yeast leavening, chemical leavening provides faster carbondioxide production. This would be useful in bakery product formulations where the elastic properties coming from gluten development are restricted and the natural flavor compounds produced during yeast leaving is undesirable (Fennema, 1996). The main difference between a baking soda and baking powder is that in formulations containing baking soda, a source of acid such as milk or yoghurt is needed in order to start the reaction. Baking powder already includes acid in the mix. Depending on the type of acid being used, either slow or fast release baking powders can be categorized in two groups; single or double acting. Double acting baking powder contains both slow and fast release acids which reacts with the sodium bicarbonate and produces gas before and during baking. Double acting baking powder is a more common leavening agent than baking soda due to its neutral flavor and ability to release gas in the oven.

Staling of cakes

Depending on the formulation and packaging conditions, cakes can be stored from weeks to several years. During storage, various reactions take place that alter the organoleptic and physical characteristics of the cake. These physical-chemical changes will cause crumb firming and loss of moisture, softness and elasticity leading to consumer rejection even if there is no health concern. The textural and flavor changes that occur during storage of bakery products are known as staling. In the literature a lot of work is focused bread staling rather than cake staling. There are several factors which control staling. These can be summarized as follows;

1. Rearrangement of starch fractions: Starch molecule consists of two major polymers; amylose and amylopectin. Amylose is a linear molecule which is formed by α-D-($1 \rightarrow 4$) glucosidic linkages with 200-2000 anhydroglucose units. Amylopectin is a branched polymer containing periodic branches with 20-30 anhydroglucose units (Figure 2).
2. Wheat proteins: it is widely accepted that staling is associated with starch crystallization. Martin et al. (1991) found that firming caused by staling is a result of entanglements and hydrogen bonds between protein fibrils and starch remnants. This finding is in contradiction with other researchers who found an increase the staling rate of bakery products that have a low protein content (Bechtel and Meisner, 1954; Prentice et al., 1954; Kim and D'Appolonia, 1977a; Kim and D'Appolonia, 1977b). Every et al. (1998) claimed that both starch-starch and starch-protein interactions are important in controlling staling mechanism. Because the amount of protein especially in cake flour is very low (7-9%), we will focus mainly on the starch-starch interactions.
3. Lipids: Rogers et al. (1988) suggested that even though the addition of shortening lowers firmness rate, it does not interact with the starch molecules and has no influence on staling mechanism. Native flour lipids have an impact on firming rates but their affect on starch retro-gradation was found to be insignificant. Some researchers found that formation of amylose-lipid complexes during gelatinization delays granule swelling, reduces amylose leaching and decreases gelatinization enthalpy (Ghiasi et al., 1982; Eliasson, 1985; Biliaderis et al., 1986). Collar et al. (2001) found that high levels of neutral lipids reduced staling in bread.



Amylose

Amylopectin

Figure 2. Schematic representation of amylose and amylopectin molecules

Starch crystallization

In baked products there are two types of staling; crumb and crust staling. Crust staling mechanism is much simpler than crumb staling. The main reason that causes staling of crust is the moisture transfer from crumb to crust and from crust to the environment. Crust staling is not so important for cakes since a crispy texture is undesirable. However, crumb staling is more complex and the result is a bake product with a tough, dry and less elastic texture (Figure 3).

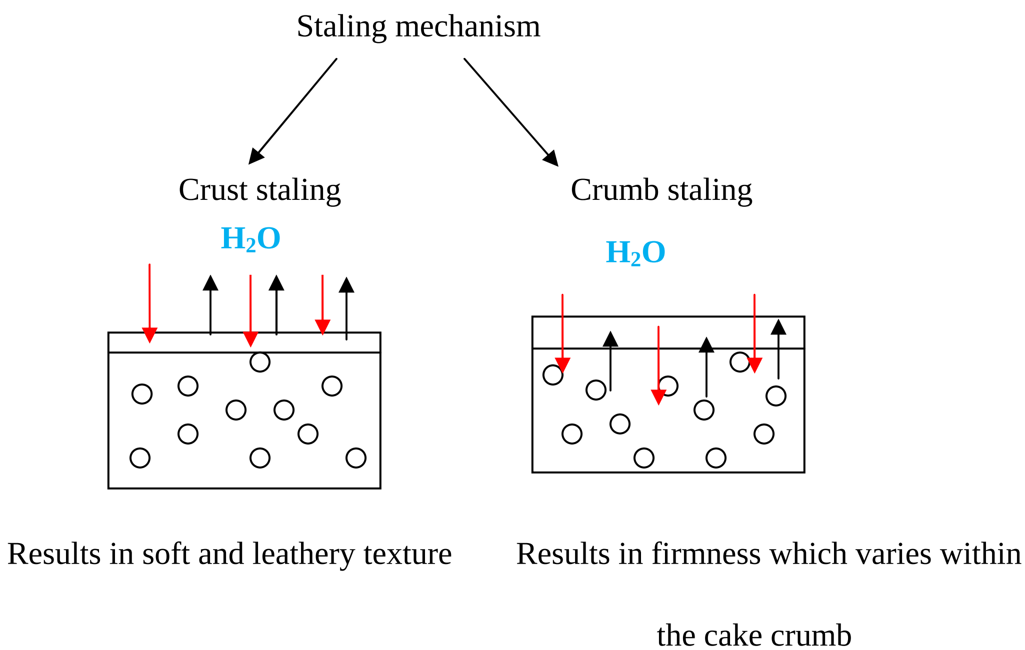


Figure 3. Types and mechanism of staling

In order to develop a key strategy to delay starch recrystallization and staling we need to understand the major theories behind it. In the following section we will summarize the pathways which lead to staling in bakery products.

Role of amylose

As we mentioned above, amylose is the linear fraction of starch that has rapid tendency to reorganize to crystallize. Kim and D'Applonia (1977) found that the solubility of amylose in

bread decreased sharply after 1 day of storage, whereas amylopectin decreased over time. When they looked at the solubilities of amylose and amylopectin in fresh bread, they found that solubility of amylopectin was 5 to 24 times higher than amylose. This showed that amylose retrogradation was almost completed by the time bread cooled down to room temperature. Another group has used different amounts of waxy starch (97 % amylopectin) to study bread staling (Ghiasi et al., 1984) and they also found that amylose fraction only contributes to staling during the first day. In addition, amylose crystals do not melt at the elevated temperatures (Knightly, 1977) which prevents reversing the staling process during heating.

Role of amylopectin

Amylopectin with its branched structure is responsible for long term staling. The first study on effect of starch on staling was done by Katz in 1928. He compared the X-ray diffraction patterns of both fresh and aged starch granules and found that the patterns of fresh bread was similar to gelatinized starch whereas the aged bread starch was similar to crystallized starch. Heating of stale bread above 100 ^{0}C would help to regain the initial freshness since the amylopectin crystals melt around 60 ^{0}C (Knightly, 1977; Hoseney and Miller, 1998; Ghiasi et al., 1984).

While the role of amylopectin and amylose are still open to discussion, most of researchers agree that there is a connection between amylopectin retrogradation/crystallization and staling.

Textural changes and starch crystallization

Staling itself is a complex process which still captures attention of many researchers. The consequences of the staling process is the main cause for product rejection and results in huge economic losses. Of the several mechanisms that control staling, the most important one is amylopectin retrogradation.

In the beginning of this project (Phase I), we searched for the current literature and made a chronological summary from 1942 to 2007 including patents and research papers. These findings are listed as a summary in Table 1.

The literature overwhelmingly points at amylopectin retrogradation and moisture migration as the leading causes for staling. Therefore, in our project we focused mainly on these two problems to control and retard staling in devils fudge cake.

Table 1. Summary of literature survey

Journal Name (Author)	**Key Strategies**	**Techniques**	**Findings**
Food Hydrocolloids (Funami et al., 2007)	Fenugreek gum with various molecular weights (MW)	Gel permeation chromatography, rapid visco analyzer (RVA)	Function of fenugreek gum depended on MW of gum. Critical MW values were standardized on the MW of the mannan backbone, lessening the effect of galactose side chains on retrogradation.
Food Hydrocolloids (Gomez et al., 2007)	Cake (sodium alginate, high ester pectin, HPMC, locust bean (LBG), xanthan (XG) and guar gum (GG))	TAXT2i, sensory panel	Hydrocolloids increased volume of cakes. The effect of hydrocolloids on firmness during storage was dependent on type. From this point of view XG was the best in reducing firmness value (40% of control cake).
Food Hydrocolloids (Chang & Lin, 2007)	Waxy corn starch, waxy rice starch with various molecular weight (MW)	High performance size exclusion chromatography, DSC	The degree of retrogradation increased with decreasing MW of starch.
Food Hydrocolloids (Zhou et al., 2007)	Wheat starch (WS), tea polysaccharide (TPS), and carboxymethyl cellulose (CMC)	DSC, X-ray diffractometer	The recrystallization rates of WS/TPS samples were lower than WS/CMC mixtures.

Food Hydrocolloids (Gomez et al., 2006)	Cakes with sodium alginate, carrageenan, pectin, hydroxyl-propyl-methycelluslose (HPMC), locust bean gum, guar gum, xanthan gum	TAXT2i, sensory panel	HPMC, xanthan gum, alginate improved sensory score the most. Only pectin-added cakes lowered the acceptance score from that of the control.
J Sci Food Agr (Guy & Sahi, 2006)	Lipase in cakes	Surface tensiometer, interfacial rheometer	Enzyme reduces surface tension and surface viscosity of batter. Surfactants produced by lipase stabilized bubbles to five greater overall expansion and volume to improve eating quality and perceived freshness of stored cakes.
Starch (Kim et al., 2006)	Guar gum and locust bean gum effect on gelation of rice starch during aging	Controlled stress rheometer	Effect of galactomannan mixtures are related to the phase separation phenomenon caused by thermodynamic incompatibility of galactomannans with amylose
Trends in Food Sci Tech (Miyazaki et al., 2006)	Bread (with modified starches in the formulation)	Review	Cross-linked (CL) barley and corn starch increased staling in bread. CL waxy corn starch decreased staling in bread. CL hydroxypropylated tapioca starch (20-30%) decreased staling rate. Ether or ester modifications to starch retarded staling.

Food Hydrocolloids (Singh et al., 2006)	Acetylation, hydroxypropylation, cross-linking, esterification of starches	DSC	Esterification and dual modification lower retrogradation
Starch (Song et al., 2006)	Octenyl succinic anhydride (OSA)	Scanning electron microscopy, X-ray diffractometer	OSA modification caused no change in crystalline pattern of rice starch up to DS .046.
Journal of Zhejiang University (Xiao-yan et al., 2006)	OSA in starch pastes	spectrophotometer	OSA decreased retrogradation of starch paste significantly.
Turk J Biol (Asghar et al., 2005)	Gums (Arabic and CMC) effect on frozen dough and final baked product	Sensory evaluation	3% Arabic received highest overall score. Arabic gave better results than CMC but both increased quality of bread.
Cereal Chemistry (Miyazaki et al., 2005)	Modified tapioca starches (hydroxypropylated (HTS), acetylated (ATS), phosphorylated cross-linked (PTS))	Scanning electron microscopy, DSC	HTS prepared bread was softer and firmed more slowly than others. PTS formed unswollen starch granules that increased firmness.
Starch (Osella et al., 2005)	Bread (corn starch, cassava starch, gum)	DSC, X-ray diffractometry	Type of crystals affected starch recrystallization. As aging occurred “B” type structure increased, “V” type structure decreased.
Food Hydrocolloids (Funami et al., 2005a)	Corn starch with different amylase content, guar gum (with various MW)	Capillary viscometer, Size exclusion chromatography, RVA	Up to a critical MW (>10^6 g/mol) guar gum was found to react easily with amylase and amylopectin to retard staling.
Food Hydrocolloids (Funami et al., 2005b)	Corn starch with different amylose content, guar gum (with various MW)	Ares strain-controlled rheometer, TA-XT2i (viscoelasticity)	Guars with relatively low MW values promoted long-term retrogradation.

International Journal of Food Properties (Gijral & Gaur, 2005)	Wheat flour incorporated with barley flour, glycerol monostearate, and sodium chloride	Instron UTM	Fresh samples had lower deformation modulus as compared to that of stored samples (24h). Additives helped restrain changes from storage (barley helped the most).
Journal of the Science of Food and Agriculture (Lakshminarayan et al., 2005)	Maltodextrins (MD) and emulsifiers	Amylograph, texture analyzer	MD improved crumb texture at 10-15% levels, glycerol monostearate improved texture, sodium steroyl lactylate did not.
Food Hydrocolloids (Singh et al., 2005)	Maize starches and their structural, thermal, and viscoelastic properties	X-ray diffractometry, DSC, Fluids Spectrometer	Sugary maize starch showed higher retrogradation than Paras and Kisan starch. High proportion of amylase and low proportion of amylopectin cause low crystallinity, gelatinization temp, and enthalpy of gelatinization.
Food Hydrocolloids (Funami et al., 2004)	Guar gum effect on gelatinization of corn starch	Capillary viscometry, size exclusion chromatography, RVA	Guars with MW higher than 10^6 g/mol interact with amylase and amylopectin and these interactions govern gelatinization behavior of starch.
Food Hydrocolloids (Funami et al., 2004)	Wheat starch in aqueous systems (non-ionic polysaccharides)	Capillary viscometry, size exclusion chromatography, RVA, Ares strain-controlled rheometer, DSC	Galactomannans increase concentration of amylase accelerations short-term retrogradation but inhibit crystallization and retard long-term retrogradation.

International Journal of Food Properties (Gill et al., 2004)	Various flours and their noodle-making properties	Instron UTM, Scanning electron microscopy, DSC	Flour with lower swelling power and small starch granules resulted in high hardness, chewiness, cohesiveness, and packability.
Food Hydrocolloids (Guarda et al., 2004)	Bread (hydroxypropylmethylcellulose (HPMC), sodium alginate, K-carrageenaan, xanthan gum)	TAXT2i texture analyzer	Hydrocolloids lowered loss of moisture. K-carageenaan had minor capacity for water retention. Regarding to increase in hardness values HPMC and alginate were the best.
Carbohydrate Polymers (Kohyama et al., 2004)	Amylopectin chain length	DSC	Longer amylopectin chains form smaller order regions and increase retrogradation.
International Journal of Food Properties (Sidhu et al., 2004)	Addition of gum acacia to Punjab wheat	Farinograph, Visco-amylograph, Instron UTM	Increase in maximum gas formation, gas retention, and softness with levels of gum acacia incorporation. Decreases firmness in storage more than xanthan gum.
Journal of Agriculture and Food Chem. (Bao et al., 2003)	Octenyl Succinic Anhydride (OSA) as a modifier of starches	Rapid Visco analyzer, DSC	Modified rice starches had a lower tendency to retrograde than native starch.
Radiation Physics and Chemistry (Ciesla & Eliasson, 2003)	Amylose-lipid complex and retrogradation processes (with gamma irradiation)	DSC	Transition takes place in irradiated starch at lower temperature with smaller enthalpy than control.

Food Hydrocolloids (Guarda et al., 2003)	Hydrocolloid use in retarding staling (sodium alginate, k-carrageenan, HPMC, xanthan gum)	TA-AT2i texture analyzer, sensory analysis	HPMC worked best as break improver regarding its effect on fresh bread quality and its anti-staling properties.
Cereal Chem. (Gujral et al., 2003)	Starch-hydrolyzing enzymes (alpha-amylase and CGTase)	TA-XT2i, DSC	Enzymes increase specific volume and reduce crumb firmness. CGTase produces better quality.
Nahrung/Food (Seyhun et al., 2003)	Microwave Cakes (effects of emulsifiers and gums)	UTM	Cakes with 25% fat and Purawave or DATEM had highest moisture retention and were the softest. Cakes with gums & emulsifiers were softer than those with gums alone.
Journal of Cereal Science (Vandeputte et al., 2003)	Rice starches and their amylopectin retrogradation behavior	DSC, visco-amylograph	Amylopectin chains with DP> 6-9 and DP> 25 inhibited retrogradation.
Journal of Food Engineering (Fukuoka et al., 2002)	Terminal extent of gelatinization (TEG) in wheat starch/water systems	DSC	TEG of wheat starch in limited water environment range from 60-100°C.
J. Agric. Food Chem. (Lee et al., 2002)	Cyclodextrin glucanotransferase	DSC, high-performance anion exchange chromatography	CGTase was as effective as Novamyl in retarding the retrogradation of bread.
Eur Food Res Technol (Leon et al., 2002)	DSC of wheat proteins	DSC	Peak endotherms ranging from 50 to 85°C. Water content of proteins determines the thermal behavior, shifting the endotherm to lower temperatures when water is not a limiting factor.

Journal of Thermal Analysis and Calorimetry (Naoi et al., 2002)	Locust-bean gum (LBG), tara gum (Tara-G), and guar gum (GG)- water systems	DSC	LBG and Tara-G melting peak as a single peak, while GG has an endothermic peak at a temperature higher than melting.
International Journal of Food Properties (Sidhu & Bawa, 2002)	Xanthan gum	Farinograph, Visco-amylograph, Instron UTM	Xanthan gum used at 0.2% provides acceptable quality bread and with extended softness and decrease in firmness for wheat flour.
Starch (Hibi, 2001)	Waxy corn starch	Sensory test, Rheoner RE3305	Addition of retrograded waxy corn starch to wheat flour increased specific volume of loaf and bread quality. After storage, the increase in bread crumb firmness was suppressed.
Starch (Karaoglu et al., 2001)	Modified wheat and corn starch in cakes	UTM, Minolta calorimeter	Quality of cake decreased by addition of dextrinized starch. 10% pregelatinized starch addition to cake recommended.
Patent #2001/0006691 A1 (2001)	Hard and soft wheat flours, dextrose, soybean oil, nonfat dry milk, fermented flavor, gum blend, vital wheat gluten, distilled monoglycerides, an enzyme blend, konjac flour, and methylcellulose	Plate and poke tests	These ingredients help provide baked good with a longer shelf life when in specific ratios.
Carbohydrate Polymers (Closs et al., 1999)	Starch/guar galactomannan systems	Light microscopy, vertical scan macroscopic analyzer, controlled strain rheometer	Starch/galactomannan systems reveal a greater structural strength of the blends than of their individual components.

J Agric Food Chem (Defloor & Delcour, 1999)	Baked dough (maltodextrins, enzymes, sucrose)	DSC, Farinograph	Sucrose addition did not affect amylopectin retrogradation. Addition of maltodextrins (1.2, 2.3, 3.6 % flour db) reduced staling. Enzymes were also found to reduce staling rate.
Journal of Food Science (Gelinas et al., 1999)	Accelerated Shelf-life test for devil's fudge cake	TA.XT2 texture analyzer	Fats, sugars, egg whites, cocoa, sodium bicarbonate reduced staling. Butter and sucrose were the best to slow cake staling compared to shortening and glucose.
Journal of Cereal Science (Armero & Collar, 1998)	Flour type, process, and anti-staling additive effect on crumb firmness during storage	Instron Food Testing Machine, Amylograph	Changes in specific volume of bread due to anti-staling additives effect crumb firmness (surfactants, alpha-amylase, etc.)
Cereal Chemistry (Buera et al., 1998)	White bread (glass transition state)	DSC, scanning electron microscopy, stereomicroscopy	Glass transition values decreased with increasing moisture content.
Cereal Chemistry (Jacobson & BeMiller, 1998)	Freeze-thaw cycle (FTC) used to accelerate and quantitate retrogradation of starch pastes	Spectrophotometer, X-ray diffractometer	Acceleration of retrogradation can be controlled by controlling the freezing rate
J. Agric. Food Chem. (Min et al., 1998)	Starch-hydrolyzing enzymes (maltose-, matotriose-, maltotetraose-producing enzymes) and the resulting amylase	DSC, HPLC analysis	Amylases that produced maltotriose and maltoteraose showed great potential as antistaling agents for bread.

Carbohydrate Polymers (Fredriksson et al., 1997)	Starch (wheat, rye, barley, maize, pea, potato) physico-chemical properties	DSC	Correlation between amylopectin/amylase and gelatinization and retrogradation enthalpies.
Carbohydrate Polymers (Jouppila & Roos, 1997)	Amorphous corn starch	DSC	Onset temperature of gelatinization around 62°C.
Carbohydrates (Rolee & Meste, 1997)	Starch-water preparations	Viscoanalyzer, laser-light diffraction, DSC	Amylase-lipid melting around 125°C.
Cereal Chem (Schiraldi et al., 1996)	Bread (with various water levels)	DSC, Instron UTM	Water poor bread was softer and the extent of starch retrogradation was lower.
Journal of Cereal Science (Mua & Jackson, 1996)	Corn starch (fractions of amylase and amylopectin with various MW)	DSC, Instron UTM	Intermediate MW amylopectin-fractions with a high degree of branching underwent more recrystallization than those with high or low MW.
Cereal Chemistry (Schiraldi et al., 1996)	Bread crumb (calorimetric investigations)	DSC, TGA, Hygroscope	Bread firmness depends on the formation of a crosslinked network rather than amylopectin crystals.
Patent # 5,362,510 (1994)	Processed starch	Rheometer	Starch gives excellent texture and inhibits degradation of food with time.
Cereal Chem (Inagaki & Seib, 1992)	Bread (waxy starch)	DSC, Instron UTM	Bread with high level of amylopectin increased firmness at a faster rate. Role of amylase is passive in staling. The higher the amount of swollen starch granules the higher the rate of firming.

J Agric Food Chem (Jovanovich et al., 1992)	Amylose-lipid complex in wheat flour, starch, and isolated complex	DSC, X-ray diffractometer	Multiple endotherms in flour and starch but only one in isolated complex.
Biotechnol. Prog. (Roos & Karel, 1990)	Sucrose and Amioca (thermal transitions)	DSC	Crystallization of amorphous materials occurs above T_g and depends on moisture content and time.
Patent # 4,684,526 (1987)	Hydrophillic lecithin blend with monoglyceride	Instron Universal Tensile Tester	The blend (with HLB value greater than 8) improves staling inhibition of a baked food product.
Patent # 3,733,208 (1973)	Microbial heteropolysaccharides comprising hexose and succinic acid	Sensory test	Incorporation into dough prevents staling and retrogradation upon storage.
Patent # 2,285,065 (1942)	Sorbitol	Moisture/Weight loss	Softness and moisture retention properties of baked product generally increase as the percentage of sorbitol is increased.

3. RESEARCH OBJECTIVES

The objectives of this study were:

- To explore different ingredient strategies to obtain the best cakes formulation with decreased staling rate
- To identify quantitative measures of textural properties from various cake formulations
- To understand the effect of ingredients on the staling rate of cakes.
- To confirm that staling is one of the most important texture related problems during shelf life in baked products
- To bring in advances in baked food formulation, manufacturing and packaging technology to slow down the starch retrogradation rate

4. MATERIALS AND METHODS

4.1 Materials

The list of the main ingredients used for this research work and their suppliers are listed in Table 2.

Table 2. List of ingredients

Name of the ingredient	Supplier
Shortening	Centrasoy
Cocoa	De Zaan
Sodium bicarbonate	Church&Dwight Co
Baking powder	ADM Arkady
Cinnamon and Vanilla	Spiceco
Flour	General Mills
Xanthan gum and Locust bean gum	Tic Gums
Pregelatinized starch and modified flour	National Starch
Enzyme (alpha amylases)	Danisco foods

4.2 Methods

4.2.1 Cake formulation

The starting cake formulation used in this project was based on a suggested formulation listed in military performance specification (**PCR-C-024).** Several changes were made to this PCR formulation to create our control formulation. Contrary to liquid eggs, we preferred to use dried eggs+water, which are easier to handle and better for sanitary reasons. Also, the cakes responded better in terms of loaf volume and distribution of air cells when dried eggs were used. We also doubled the amount of baking powder and included baking soda in the formulation. Together with baking powder, baking soda improves the oven rise.

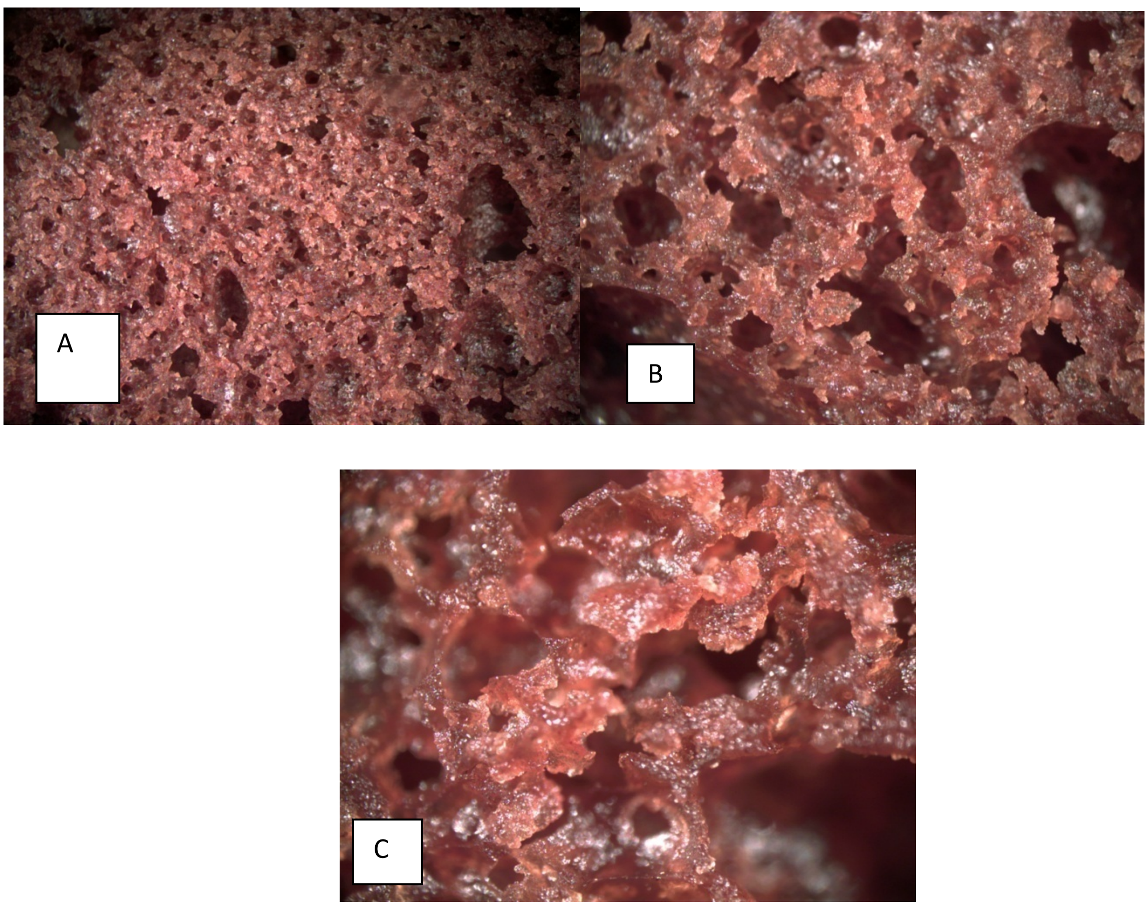


Figure 4. Streomicroscope images of control cake A) 0.75X objective B) 2X objective C) 5X objective

In cake systems, maltodextrins have various applications as a fat replacer and a water binder. However, we excluded the maltodextrin from our formulation since it adversely affected the loaf volume and resulted in a closed structure and increased stickiness of the product.

The water activity of this new control cake was 0.87 with a specific gravity of 0.996. The cake lost approximately 11% of the batter weight during baking in an oven at 340 F for 50 min.

PCR -C-024A formulation **Rutgers modified formulation**

Ingredient	Amount of each ingredient for 100g batter	Ingredient	Amount of each ingredient for 100g batter
Shortening	11.09	Shortening	11.71
Sugar	26.62	Sugar	27
Flour	15.84	Flour	16
Egg (whole frozen)	15.32	Egg (dried)	3.8
Starch	1.00	Starch	1
Salt	0.73	Salt	0.75
Baking powder	0.38	Baking powder	0.75
Baking soda	0.00	Baking soda	0.09
Potassium sorbate	0.10	Potassium sorbate	0.1
Guar gum	0.10	Guar gum	0.1
Xanthan gum	0.10	Xanthan gum	0.1
Cinnamon	0.28	Cinnamon	0.28
Cocoa	5.00	Cocoa	5
Water	18.55	Water	30
Glycerol	3.23	Glycerol	3.23
Vanilla (liquid)	0.09	Vanilla (liquid)	0.09
Maltodextrin	1.48	Maltodextrin	0

4.2.2 Preparation of cake batter and baking protocol

The ingredients were mixed by the use of a Hobart mixer (Hobart Corp., Troy, OH). First, shortening and sugar were mixed. The next step in mixing involved addition of the remaining dry ingredients (flour, baking powder, baking soda, cocoa, dried egg powder, gums, antimicrobial agents, cinnamon and starch). The liquid ingredients (glycerol, water and vanilla) were added to the previously mixed dry ingredients gradually to avoid formation of clumps in the batter and to get homogenous distribution. The cake batter was deposited to Pyrex plates in the initial baking

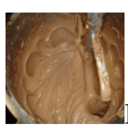
trial of cakes at Rutgers University Food Science Department. This allowed us for a better observation of the cake during and after baking. For the plant trials at Rutgers Food Manufacturing Technologies facilities, we used paper trays provided by the Sterling Foods. The flow diagram for the production of cake samples at Rutgers University Food Science department is summarized in Figure 5.


Mixing at high 2min (shortening & sugar)


Mixing at low 2min (dry ingredients)


Mixing at high speed 2 min (1/3 liquid ingredients)


Mixing at high speed 3 min (1/3 liquid ingredients)


Mixing at high speed (1/3 liquid ingredients)


Deposit batter to a Pyrex plate

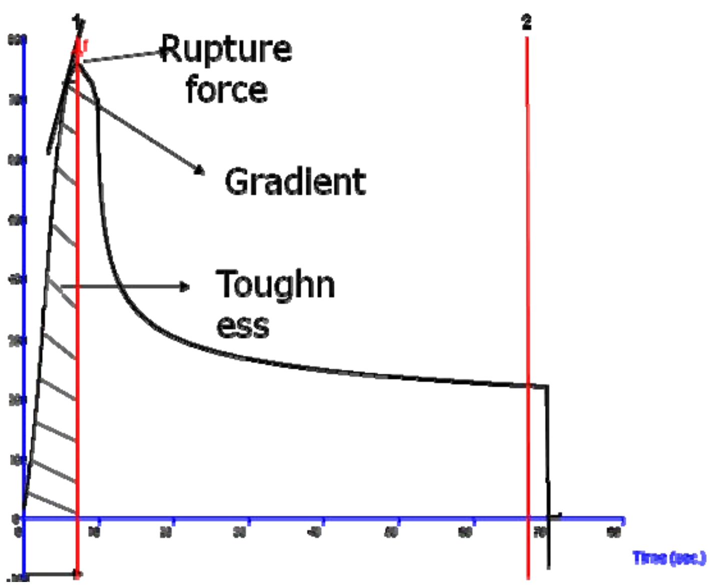

Leveling of the batter

Baked cake (350 F, 50min)

Figure 5. Flow diagram of preparation and baking of cakes at Rutgers University Food Science Department

4.2.3 Texture Measurements

Textural analysis was done by uniaxial compression at 1mm/s probe speed and strain level of 60% with a 5mm diameter Al probe. Analysis of the force deformation curves was done using an operator independent macro which was developed and validated by Dr Kokini's laboratory. Measurements were done for ten replicates. A typical force deformation curve corresponding to the deformation of the cake samples used in this study was shown in Figure 6.



Rupture distance (mm)

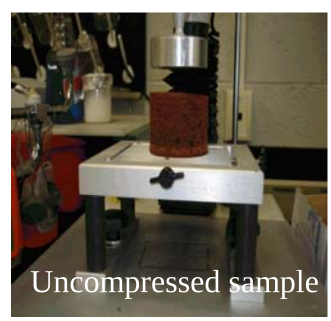


Figure 6. A typical force-deformation curve

The quantitative measures of texture derived from a deformation curve are:

Firmness : Force in N required to compress the sample by a pre-set distance (e.g. 60%)

Springiness : % recovery defined as

(Force at 60 seconds/ Fmax)*100

Rupture Force : The maximum force exerted by the probe before the sample ruptures is a measure of the hardness of the sample

Rupture Distance : The distance traveled by the probe at the point of rupture

Gradient: is the slope of the linear portion of the deformation curve and is a measure of the elasticity of the sample

4.2.4 Specific gravity

Specific gravity is determined by dividing the weight of a material by the weight of an equal volume of water (Penfield and Campbell, 1990). To determine the specific gravity of cake batter, a graduated cylinder with a 50 ml capacity was taken and the weight of both water and cake batter were measured. The large air pockets which could occurred while pouring the batter into the cylinder were removed by lightly tapping the beaker.

4.2.5 Moisture content

Cake samples were crumbled from the interior crumb of the cake and dried to constant weight at 135 ^{o}C on predried Al dishes. After drying to a constant weight they were transferred into desiccators to cool down to room temperature. Percent moisture content of cake samples were determined as follows:

$$\% \text{ Moisture Content} = \frac{\text{[wt. of initial sample – wt. of dried sample] (g)}}{\text{wt. of initial sample (g)}} \text{ X 100}$$

4.2.6 Water activity

Water activity was determined using a Decagon Aqua Lab CX-2 water activity meter (Pullman, WA). Water activity was measured both on fresh cakes and cakes stored for shelf life analysis. Prior to each test, the meter was turned on and allowed to warm up for 30 minutes. The water activity meter was calibrated by filling a plastic disposable cup half full with a saturated potassium chloride solution which had a a_w similar to that of a cake. Each sample was measured

by covering the bottom of a plastic disposable cup with a small portion from the interior crumb of the cake, placing the cup into the sample holder, and taking the reading.

4.2.7 Volume and symmetry

The volume and symmetry indices were calculated using a layer cake measuring template (Figure 7) as described in AACC Method 10-91 (AACC, 1983). Cakes were sliced in half. The interior face of half of the cake was placed towards the template. Volume index was calculated by adding the cake’s height at the center and at points halfway between the center and the outer edges (Figure 7):

Volume Index = B + C + D

Symmetry index was calculated using the following equation:

Symmetry Index = (2C - B – D)

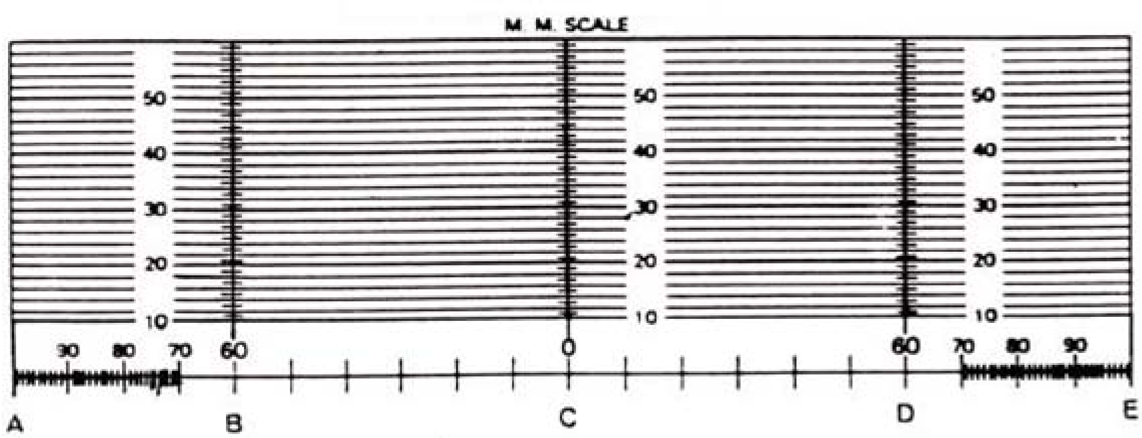


Figure 7. AACC cake measuring template

4.2.8 Differential scanning calorimeter measurements

Thermal analysis was performed using a Mettler Toledo DSC 822 equipped with STARe Thermal Analysis System software. Approximately 10mg of the sample was weighed into Al crucibles of 40 µl capacity. The instrument was calibrated using indium as a standard. The samples were scanned from -50°C to 200°C at a heating rate of 10°C/min, using an empty crucible as a reference. The glass transition temperature was measured as the temperature

corresponding to the midpoint of change in heat capacity of the sample. Measurements were done in duplicates.

4.2.9 X-Ray diffraction analysis

The wide-angle x-ray scattering (WAXS) patterns of cake samples were obtained by use of a Bruker HiStar area detector and an Enraf-Nonius FR571 rotating anode x-ray generator equipped with a graphite monochromator (Cu Kα; λ = 1.5418 Å) operating at 40 kV and 50 mA. All of the data were collected at room temperature over a period of about 1800 seconds. The sample to detector distance was 9.0 cm and the standard spatial calibration was performed at that distance. Scans were 4 degrees wide in omega (ω) with fixed detector, or Bragg, angle (2θ) of 25 deg, and fixed χ angle of 0 and freely spinning Φ angle. In all cases, the count rate for the area detector did not exceed 100,000 cps. The samples were prepared by forcing the fine cake into the open end of a 1 mm special glass x-ray capillary. The open end of the capillary with sample was forced into clay mounting on the goniometer head. The center of the capillary was centered on the instrument. The intensity versus 2θ plots was analyzed for crystalline to amorphous ratio by the method of Cheetham and Tao (1998) as shown in Figure 8.

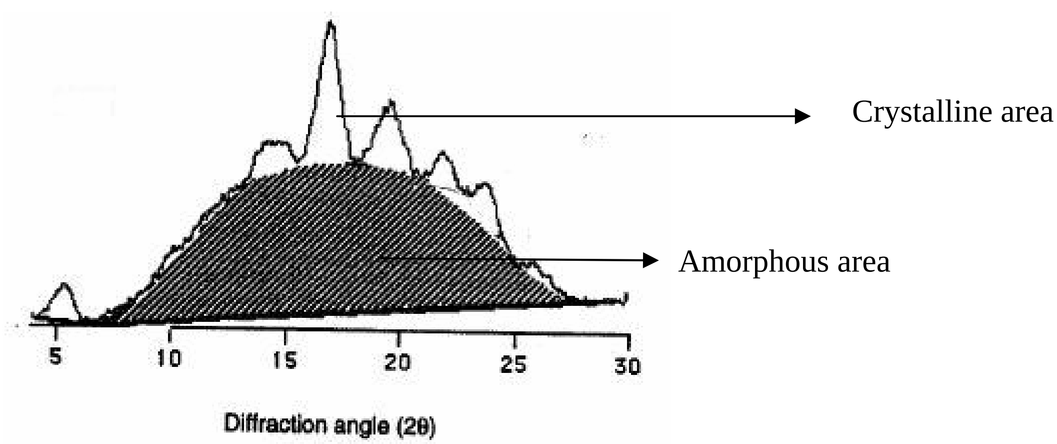


Figure 8. Calculation of crystalline to amorphous ratio in maize (Cheetham and Tao, 1998)

The intensity versus 2θplot for each sample was fitted into the SigmaScan Pro software for image analyses. A smooth curve which connected the peak baselines was plotted on the diffractograms. The area above the peak base line corresponded to the crystalline portion and the lower area between the smooth curve and a linear baseline which connected the initial and final 2θ values was taken as the amorphous region. The ratio of the areas corresponding to the crystalline and amorphous region was calculated as a measure of relative crystallinity (Figure 9):

$$\text{Relative Crystallinity (\%)} = \frac{\sum \text{Area under peaks}}{\text{Area of amorphous region}}$$

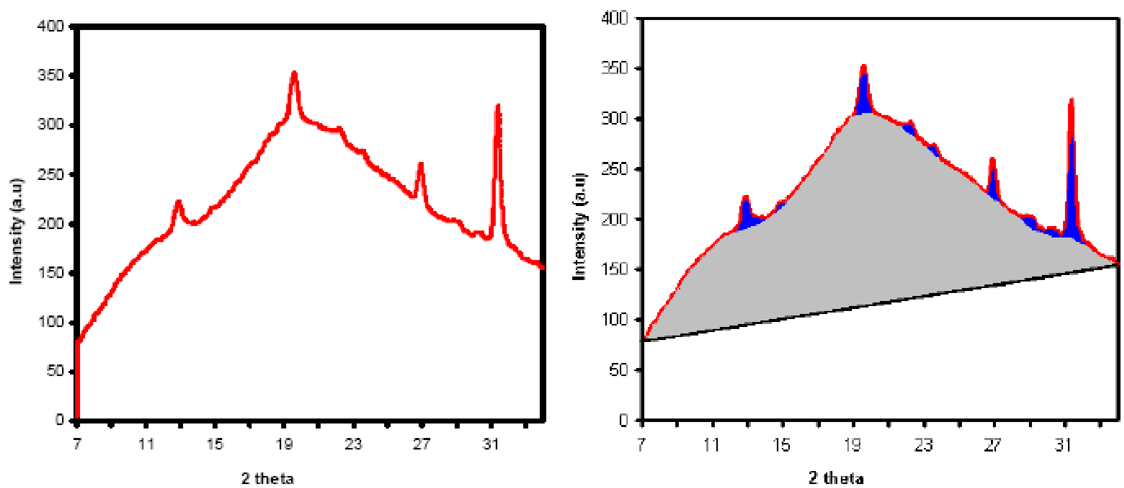


Figure 9. Relative crystallinity calculations for cakes

4.2.10 Structural characterization by image analysis technique

Non destructive X-ray microtomography technique (XMT) was used to analyze cellular structure of the samples. Cake samples were taken from the center of each tray and put into transparent zip lock bags in order to avoid from moisture loss.

For getting images we used a high resolution microtomography (< 2µm) SkyScan 1172 (SkyScan, Belgium). The micro computed tomography captures 3D images by illuminating the

object with X-ray beams. XRT consists of a monochromatic X-ray source, a rotatable stage and a panoramic detector. Cross sectional images of cake samples were analyzed by the help of a software called SigmaScan Pro (version 4.0) (Jandel Scientific, CA). Cross sectional images were chosen arbitrarily from the 3D images. A series of procedure was applied to increase contrast and identify the pores. The image is converted from black pixels to either of red, green, yellow or blue colors. The software could only analyze this group of colors. The number of cells, area and perimeter of each cell and wall were parameters of interest. The uniformity of pore size distribution was calculated by a value called polydispersity index (PDI) which ranges between 1 and infinity. If the PDI value is closer to 1 then the cell size distribution is more uniform. PDI value can be calculated as follows;

$$PDI = \frac{\sum \frac{A_i N_i}{\sum N_i}}{\sum \frac{(A_i^2 N_i)}{\sum (A_i N_i)}}$$

where A_i is cell area and N_i is number of cells having A_i. Average cell wall thickness can be calculated from the equation below;

$$t_{wall} = \frac{A_{solid}}{\sum_i P_i}$$

where A_{solid} is the solid portion of the cross sectional area, and P_i is the perimeter of air cells. Image analysis technique was used to sensitively map the differences in structural characteristics of cake samples such as cell density (number of cells per unit area), average cell wall thickness (t) and cell wall thickness to radius ratio (t/R).

5. RESULTS AND DISCUSSION

5.1 Accelerated Shelf life testing of various ingredients and optimization of formulations

The effect of each type of ingredients on slowing the staling rate of devil's fudge cake was first tested separately in order to better understand the ingredient and texture relations. We tested the following ingredients:

1. National Starch Homecraft Flour – retards staling by holding water inside the product through a physical modification of the flour.
2. Danisco Powerfresh - Increases softness, extends shelf-life , increases the crumb strength, by utilization of bacterial amylases.
3. Danisco Maxlife U4 – Fungal and bacterial amylase; increases shelf life in bread and bakery products; improves softness

   Danisco Maxlife E5 – fungal amylases. Same function with Maxlife E5 but inactivates during baking.

4. Xanthan gum , guar gum at higher concentrations (0.5%, 0.14%)
5. Polysorbate 60/80 from Protameen Chemicals Inc.
6. Danisco-Grindsted GA 1350 – Improve whipping of cake, improved grain and texture, increased tenderness of low-fat products.
7. Danisco Litesse Polydextrose – fat replacer, sweetener, has influence on staling

In this final report we are avoiding to show our previous data on shelf life of cakes formulated with Sterling Foods' ingredients. All the results shown refer to the data of reformulated cakes with new ingredients which are different than the Sterling Foods' ingredients. Table 4 summarizes the ingredients tested and percentages used in various formulations. The formulations include homecraft (HC) flour (pregelatinized/physically modified flour from National Starch), Maxlife E5 (ML) (enzyme (amylases) mix from Danisco), Polysorbate 60 (PS60) (emulsifier), locust bean gum and polydextroses. In all of the formulations mixture of gums were used due to their synergistic action. In all the recipes we used mixture of guar and xanthan gum except one formulation in which we tested the synergistic effect of guar and locust bean gum (LBG). Locust bean gum has longer chain length and higher in molecular weight (MW) than xanthan gum which makes it more effective in retardation of staling.

Table 4. Percentages of each ingredient in various different formulations

Ingredients	**Control**	**Maxlife E5**	**Homecraft**	**PS60**	**LBG**	**PD5**	**PD10**	**(PD5+Emulsifier)**
Shortening	11.22							
Sugar	26			25.55				
Flour	16.87	16.87	15.36			16.50	16.14	15.77
Egg (dried)	3.78							
Modified Starch	0.99							
Salt	0.72							
Baking powder	0.75							
Baking soda	0.15							
Potassium Sorbate	0.09							
Polysorbate60	0.45							
Guar gum	0.09							
Xanthan gum	0.09				0			
Cinnamon	0.28							
Cocoa	4.98							
Water	29.76							
Glycerol	3.17							
Vanilla	0.09							
Enzyme (amylase)	0.01	0	0	0	0	0.37	0	0.37
Homecraft	0	0	1.51	0	0	0	0.73	0
PS60	0	0	0	0.44	0	0	0	0.73
Maxlife enzyme	0	0.01	0	0	0			
LBG	0	0	0	0	0.09			

Initially we performed accelerated shelf life testing on cake samples in order to get a quick evaluation about each ingredient on the staling rate. Measurements were done by storing cake samples at 33 % RH, 4 ^{o}C and 33% RH, 25 ^{o}C for 4 and 8 days. Third storage condition consisted of a cycle from a high temperature (60 ^{o}C, 33 % RH, 2 days) to a lower temperature (4 ^{o}C, 33% RH, 2 days). Regardless of the storage temperature all the textural measurements of the cake samples were done after they equilibrate to room temperature.

In all cake formulations flour, dried eggs and salt contribute to toughness whereas sugar and shortenings tenderize. The added water acts as a plasticizer and the flour and sugar balances this effect. Baking powder together with baking soda and egg white improves the oven rise and cake volume. Initial textural measurements of cake samples showed that the maximum force and

toughness value for control and enzyme containing formulation was the highest whereas the HC cake the lowest (Table 5).

After storage at 25 ^{o}C and 33 % RH the force values of MaxLife (ML) and PS60 cakes were very close to each other and the lowest among the cakes samples. However the toughness value of ML cake was lower than the PS60 cake being 60.24 and 64.13, respectively. Surprisingly both ML and PS60 cakes responded negatively to storage conditions at 4 ^{o}C and 33 % RH showing higher toughness and force values. Homecraft (HC) cake responded best to this storage condition since the HC flour itself is claimed by National Starch to have freeze-thaw stability. After storage of cakes for 8 days at 4 ^{o}C and 25 ^{o}C and 33 % RH the textural data shows that the HC cake responded better as compared with Control and ML cakes (Tables 8-9).

In order to see the effect of LBG-Xanthan gum on staling, the results of this cake should be compared with control cake since in each formulation GUAR gum-Xanthan gum has been used. Our findings with the LBG cake is in parallel to the literature. In any storage condition LBG cake responded better than the control cake.

According to results of uniaxial compression tests hardness and toughness values of all samples increased as the storage time increased regardless of the differences in formulation. The increase in hardness and toughness values were highest for temperature cycled (60 ^{o}C-4 ^{o}C) cakes, due to an initial increase in mobility at high temperatures and then blocking of mobility at a lower temperature (Table 10). The max toughness value for the control cake was approximately 189 Ns after performing temperature cycle on the cake. All the cakes except the formulation with increased amount of polydextrose (PD10) had lower toughness values than the control cake.

The moisture losses during baking of cakes were 10.49, 11.31, 10.00, 10.25 and 10.30 % (wet basis) for control, HC, ML, PS60 and LBG cakes, respectively.

Table 5.Initial textural parameters of cake samples baked inside Pyrex plates at Rutgers University Food Science department

Sample	**Force (N)**	**Springness**	**Rupture Distance (mm)**	**Toughness (Ns)**	**Gradient**
Control	8.05±0.52	49.73±0.43	10.03±0.28	43.14±2.54	0.88±0.19
Maxlife	9.01±0.96	50.73±0.60	10.13±0.28	42.83±2.95	0.88±0.16
Homecraft	5.28±0.29	48.92±0.39	10.11±0.29	27.54±2.44	0.64±0.02
Polysorbate60	6.46±0.93	48.12±0.65	9.53±0.41	31.16±4.71	0.65±0.07
Locust bean gum	5.92±0.48	50.65±0.96	9.91±0.16	28.61±3.04	0.57±0.04
Polydextrose5g	6.86±0.43	50.72±0.44	10.13±0.30	35.37±1.49	0.83±0.07
Polydextrose10g	8.00±0.50	50.49±0.48	10.00±0.23	42.65±4.42	0.87±0.19

Table 6. Textural values of cake samples stored at 25 ^{o}C 33% RH for 4 days

Sample	**Force (N)**	**Springness**	**Rupture Distance (mm)**	**Toughness (Ns)**	**Gradient**
Control	15.05±1.40	43.87±0.69	9.87±0.24	84.83±7.63	1.67±0.53
Maxlife	12.33±1.43	43.37±1.06	9.78±0.28	60.24±6.98	1.13±0.14
Homecraft	14.20±1.26	43.14±0.78	9.43±0.39	73.77±5.30	1.48±0.24
Polysorbate60	12.22±1.25	43.52±0.89	9.72±0.42	64.13±7.07	0.95±0.20
Locust bean gum	13.79±1.02	43.50±0.91	9.58±0.20	69.45±4.70	1.20±0.18
Polydextrose5g	15.04±1.48	42.06±1.13	10.12±0.14	81.06±13.00	1.99±0.18
Polydextrose10g	12.68±0.71	44.19±0.71	10.61±0.38	74.86±3.96	1.51±0.36

Table 7. Textural values of cake samples stored at 4 ^{o}C 33% RH for 4 days

Sample	**Force (N)**	**Springness**	**Rupture Distance (mm)**	**Toughness (Ns)**	**Gradient**
Control	13.94±1.22	40.75±0.41	9.49±0.51	80.06±10.12	1.93±0.62
Maxlife	14.54±1.29	39.52±0.91	9.52±0.29	76.59±11.79	1.11±0.06
Homecraft	12.62±1.07	41.71±0.64	9.46±0.36	68.90±7.71	1.30±0.33
Polysorbate60	14.93±2.24	39.32±0.89	9.60±0.35	83.54±12.79	0.96±0.33
Locust bean gum	13.57±1.88	40.25±1.06	9.60±0.32	66.93±9.29	1.25±0.22
Polydextrose5g	21.49±2.40	38.53±1.22	9.98±0.40	129.38±9.30	3.25±0.48
Polydextrose10g	18.37±1.28	38.89±0.48	10.31±0.60	111.32±7.62	2.35±0.25

Table 8. Textural values of cake samples stored at 25 ^{o}C 33% RH for 8 days

Sample	**Force (N)**	**Springness**	**Rupture Distance (mm)**	**Toughness (Ns)**	**Gradient**
Control	36.78±4.38	39.06±1.05	9.46±0.22	178.62±25.55	4.75±1.02
Maxlife	21.79±1.34	38.50±0.53	9.76±0.27	120.50±12.13	1.60±0.14
Homecraft	21.24±1.72	40.96±0.67	9.60±0.12	112.25±13.35	1.86±0.29
Polysorbate60	15.26±1.38	41.34±0.35	9.81±0.30	82.81±6.27	1.04±0.14
Locust bean gum	20.19±0.57	40.58±0.64	9.75±0.32	104.60±9.35	1.70±0.15
Polydextrose5g	23.54±4.60	39.64±1.74	10.03±0.25	120.36±14.16	2.71±0.98
Polydextrose10g	36.00±0.86	38.20±0.55	9.74±0.18	185.60±1.59	0.12±0.06

Table 9. Textural values of cake samples stored at 4 ^{o}C 33% RH for 8 days

Sample	**Force (N)**	**Springness**	**Rupture Distance (mm)**	**Toughness (Ns)**	**Gradient**
Control	17.19±1.36	40.03±0.67	9.58±0.19	91.25±11.86	1.68±0.34
Maxlife	15.49±1.95	41.11±0.92	9.58±0.20	81.91±12.01	1.13±0.25
Homecraft	13.55±1.59	40.47±0.78	9.71±0.12	70.58±7.14	0.95±0.20
Polysorbate60	7.50±0.38	43.13±0.55	9.93±0.35	36.44±4.09	0.81±0.13
Locust bean gum	20.16±2.53	38.04±0.99	9.73±0.19	102.07±14.65	1.87±0.29
Polydextrose5g	20.56±1.20	39.03±0.63	10.00±0.21	115.97±8.74	2.23±0.41
Polydextrose10g	26.46±3.58	36.46±0.50	10.28±0.31	146.45±6.85	2.33±0.01

Table 10. Textural values of cake samples cycled from high (60 ^{o}C 33% RH) to low temperature (4 ^{o}C, 33% RH)

Sample	**Force (N)**	**Springness**	**Rupture Distance (mm)**	**Toughness (Ns)**	**Gradient**
Control	35.55±2.27	41.07±0.64	9.70±0.19	189.61±17.52	2.98±0.36
Maxlife	40.96±8.61	35.85±2.05	9.71±0.29	198.82±43.54	3.73±0.71
Homecraft	21.00±1.28	41.79±0.55	10.04±0.32	113.46±8.89	1.86±0.22
Polysorbate60	48.91±3.97	33.75±0.94	9.54±0.27	264.85±41.13	3.26±0.58
Locust bean gum	37.41±4.49	35.07±1.08	9.49±0.30	191.00±26.00	3.43±0.54
Polydextrose5g	30.71±1.40	39.31±0.48	10.02±0.35	148.15±13.40	3.65±0.47
Polydextrose10g	42.43±3.80	35.48±0.91	9.95±0.26	223.71±17.89	0.10±0.03

Glass transition temperature is defined as the temperature interval where the food material passes from a brittle solid state to a viscous state. Glass transition is a characteristic property which affects the physical and textural properties. The end point quality of food materials can be controlled through their glass transition temperature (Tg) which has influence on production characteristics.

Table 11. Glass transition temperatures of cake samples stored at 4 ^{0}C, 33% RH for 8 days

Type of cake	**Refrigeration temperature (4 ^{0}C)**		
	To	**Tp**	**Te**
Control	27.35±0.35	28.67±0.42	29.88±0.14
Homecraft	26.78±1.31	26.72±0.05	27.77±0.06
Polysorbate60	26.49±0.39	27.54±0.12	29.01±0.08
LBG	26.51±0.66	29.09±0.44	32.64±1.44
ML enzyme	13.71±0.19	21.64±0.49	24.80±0.41
PD5	14.14±0.18	17.35±0.45	20.14±1.01
PD10	12.05±0.12	15.31±0.32	18.47±0.56

Table 12. Glass transition temperatures of cake samples stored at 25 ^{0}C, 33% RH for 8 days

Type of cake	**Room temperature (25 ^{0}C)**		
	To	**Tp**	**Te**
Control	25.79±0.06	28.14±0.35	30.72±0.45
Homecraft	27.05±0.27	30.07±2.26	32.19±1.85
Polysorbate60	26.45±0.06	27.82±0.03	29.63±0.29
LBG	26.86±0.05	28.16±0.05	29.04±0.32
ML enzyme	26.04±0.04	28.53±0.06	32.75±0.28
PD5	13.10±0.60	17.38±0.00	19.45±0.32
PD10	12.84±0.51	15.41±0.13	19.97±0.26

Table 13. Glass transition temperatures of cake samples cycled between 60 and 4 ^{0}C, 33% RH for 4 days

Type of cake	**Heating and cooling cycle (60-4 ^{0}C)**		
	To	**Tp**	**Te**
Control	26.58±0.01	32.49±0.20	33.58±0.32
Homecraft	27.00±0.33	28.63±0.81	30.77±0.66
Polysorbate60	28.88±0.02	29.22±0.27	30.60±0.27
LBG	27.11±1.90	31.79±0.06	33.51±1.05
ML enzyme	26.50±0.30	27.82±0.01	29.18±0.19
PD5	15.46±0.24	18.66±0.32	20.28±2.36
PD10	15.16±0.13	19.91±0.25	21.40±0.45

The mechanical properties of food materials go through a dramatic change at storage temperatures around the glass transition temperature. The mobility of polymeric materials increases as the material passes from a glassy to rubbery state. The glass transition temperature of the "temperature cycled" cakes were highest as compared to the other storage temperatures (Tables 11-13). The higher the Tg gets the lower the mobility became. The low mobility of water in the polymer chains increased resistance to deformation which also contributed to higher toughness values.

5.2 Long term shelf life testing of various ingredient strategies

Long term shelf life tests were performed on cakes which were baked at Rutgers Food Science department and sealed inside polytrays at Rutgers-Food Manufacturing Technologies facilities. Cakes produced and formulated with different ingredient strategies were sealed and stored at 50 ^{0}C for 1 month. The changes in textural parameters were followed every week during this period. It was found that for all the cake formulations there was an increase in both hardness and toughness values whereas springiness values decreased. The basic differences within formulations were created by incorporation of gums, enzymes, soluble fibers, emulsifiers, and modified flours in the formulation. Surfactant (polysorbate 60) and enzyme (alpha amylase) based formulations yielded both the lowest hardness and toughness values (Figures 10 and 11). The tendency of amylose chains to retrograde and increase hardness/toughness of the cakes can be reduced by the addition of emulsifiers to the formulation Emulsifiers have the ability to combine with the amylose chain which blocks its diffusion in the initial cake setting. The purpose of using emulsifiers as antistaling agents is, they increase initial softness. However, they have no influence on moisture migration.

Enzymes, basically alpha amylases have the ability to slow down the rate of crumb hardening and moisture migration by breaking down the amylopectin chains in to smaller units. While using enzymes in the formulations amount and type of enzyme is quite important because of quality aspects. Excessive enzyme use might yield a sticky and difficult to slice cake.

The second group of ingredients which improved the textural properties during 1 month of storage at 50 ^{0}C are the formulations with Locust Bean Gum (LBG) and Polydextrose (PD). Locust bean gum is one of the high molecular weight water soluble polysaccharides which is more effective than the low molecular weight gums. Hydrocolloids have the ability to reduce staling rate by binding water to their structure. Polydextroses belong to the group of soluble fiber which can be synthesized from dextrose together with sorbitol and citric acid. Besides its main function as a fat, sugar and starch replacer it can also be used as a humectant, stabilizer, and thickening agent.

Springiness of each sample dropped to 2/3 of its original value (Figure 12). But we didn't see a dramatic effect of ingredient variation on the springiness value over time. As a textural parameter springiness of cake samples shows the potential of the cake to recover back to its original height after compression. Practically, this recovery will refer to the elasticity of the sample. In our formulations we focused to decrease and control the increased hardness and toughness in staled cakes. The constant springiness values showed us that our ingredients were not altering the elastic material property which was an expected result.

From the accelerated and long shelf life testing of our initial trials we concluded that a combination formulation of enzyme, modified flour, high MW gum, emulsifiers and surfactants will work synergistically to slow down the staling rate in cakes.

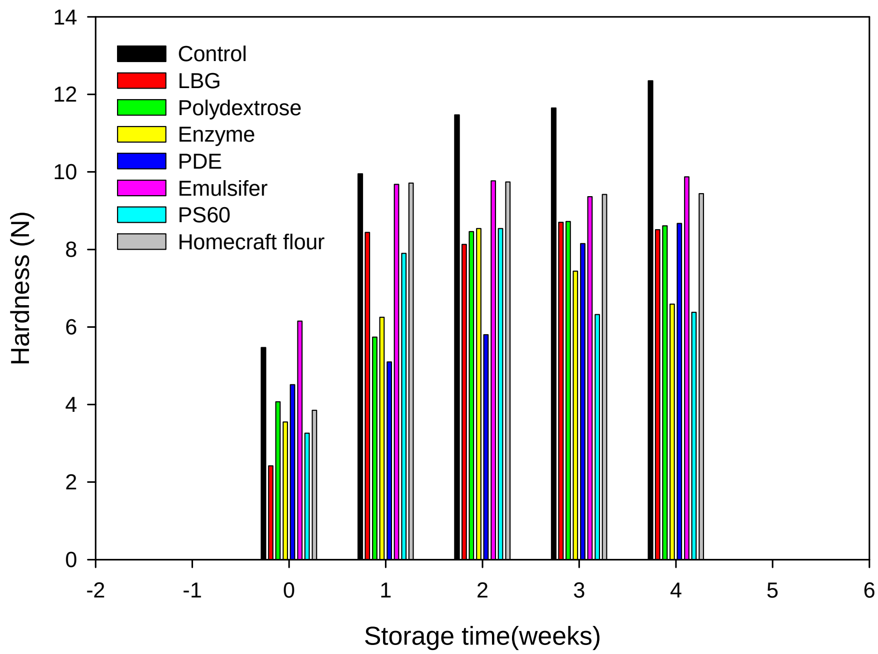


Figure 10. Change in hardness values of cake samples with different formulation over 1 month of storage at 50 ^{0}C.

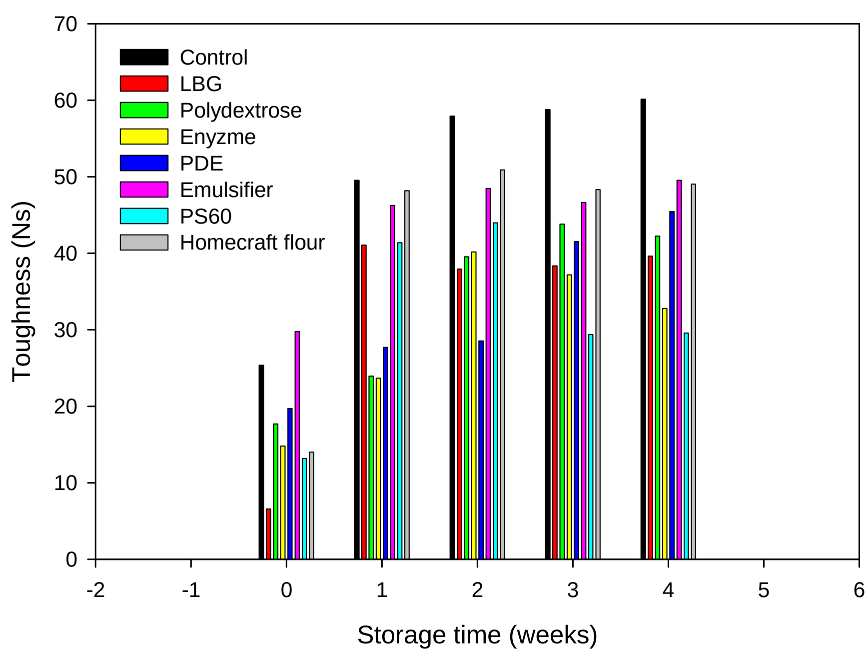


Figure 11. Change in toughness values of cake samples with different formulation over 1 month of storage at 50 ^{0}C.

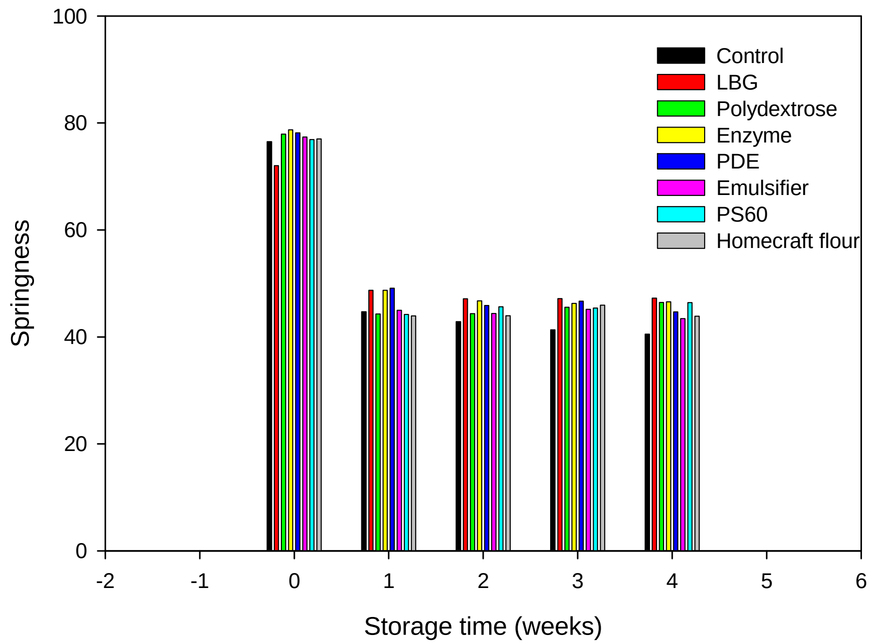


Figure 12. Change in springiness values of cake samples with different formulation over 1 month of storage at 50 ^{0}C.

5.3 Scale up of cake production

5.3.1 Determination of scaled up mixing and baking conditions for the control cake

The baking protocol which was developed in the Rutgers Food Science department was scaled up for production at Food Manufacturing Technologies (FMT). For this purpose we used a 20 Quart Hobart mixer with a batch size of 20 lb. The mixing procedures were kept the same as the lab trials which are summarized in the following chart (Figure 13).

Mixing at high speed 2min (shortening & sugar)

↓

Mixing at low speed 2min (dry ingredients)

↓

Mixing at high speed 2 min (1/3 liquid ingredients)

↓

Mixing at high speed 3 min (1/3 liquid ingredients)

↓

Mixing at high speed 3 min (1/3 liquid ingredients)

Figure 13. Mixing flow chart

The specific density of control batter at the end of mixing was 0.89 g/cc at 25 ^{0}C. Previous scale up trials were done by the use of a convection oven which caused problems on the cake surface such as thick crust formation and sugar crystallization. Use of a rotary type of oven (Reeds rotary oven) without convectional heat transfer helped us to handle these problems. The maximum capacity of this oven was eight tray cakes at one run. The oven was preheated to 176 ^{0}C one hour prior to baking. Initial trials to set up the baking conditions were done on control cake. The baked and cooled control cake was tested in terms of moisture content, water activity and textural properties. Cakes were removed from the oven after 51, 53, 55 and 57 minutes of baking. All the moisture content and water activity levels were within the specification limits ($aw<0.89$, $MC>18\%$). Textural parameters of control cake which was baked for 51 min in the rotary oven had the closest textural scores to the control cake which was produced at Rutgers Food Science department (Table 14).

Table 14. Quality parameters of scaled-up control cake

Cake sample	Hardness (N)	Springiness	Toughness (N.s)	Water activity	Moisture content (%)
57 min FMT	8.50	60.90	43.05	0.869	25.15
55 min FMT	7.56	80.33	34.67	0.868	25.16
53 min FMT	7.37	85.21	34.55	0.864	26.18
51 min FMT	5.83	82.95	25.00	0.866	27.18
Control cake baked at RU Food Science (51 min)	5.47	76.50	25.36	0.874	23.65

The initial weight of the control batter was 998 g. After baking it dropped to 881-876 g depending to the increase in baking time. We successfully scaled up the baking procedure at FMT by using a 20 Qt Hobart mixer and a rotary type oven with a baking temperature of 176 ^{0}C and baking time of 51 min.

5.3.2 Testing of various ingredient strategies and combination of these ingredients in two different formulations

Various ingredient strategies defined in section 4.1 of this report were baked inside paper trays and sealed in poly trays. Two different formulations which combines the ingredients; Homecraft flour (modified flour), polydextrose (soluble fiber), polysorbate 60 (surfactant), emulsifier, locust bean gum, enzyme (alpha amylase) were also produced together with the cakes which testes the effect of individual ingredient use. The percentages of each formulation are given Tables 15-24. Addition of emulsifiers together with surfactants decreased the density of batter. The samples were stored at 37 and 50 ^{0}C for a total of 3 and 6 months, respectively. 10 trays of control, combination formulation #1 and combination formulation #2 were sent to Natick for shelf life testing for the following time and temperatures, 2 and 4 weeks at 50 ^{0}C and 3 and 6 months at 37^{0}C.

Table 15. Percentages of control cake formulation

FOOD MANUFACTURING TECHNOLOGY DEMONSTRATION FACILITY

PRODUCTION FORMULA AND INSPECTION PROCEDURES

Revision Date:3/5/08

Supersedes: 12/20/07

Product Name: Devil's Fudge Cake in Polymeric Tray

Material ID: 674-Rutgers-Control

Product Formula:

Description	Mat ID	Recipe	Form %	Quantity	UOM
Water	RUT-90000	30.00	30.00%	2721.6	gram
Sugar, Extra Fine	RUT-201	27.00	27.00%	2449.4	gram
Flour Cake	RUT-103	16.00	16.00%	1451.5	gram
High Ration Shortening	RUT-315	11.71	11.71%	1062.3	gram
Glycerol	STE-1902	3.23	3.23%	293.0	gram
Cocoa	RUT-614	5.00	5.00%	453.6	gram
Whole Eggs, Dried	STE-401	3.80	3.80%	344.7	gram
Baking Powder, Double Acting	RUT-904	0.75	0.75%	68.0	gram
Salt, Non Iodized	STE-1803	0.75	0.75%	68.0	gram
Starch, Instant, Granular	STE-715	1.00	1.00%	90.7	gram
Vanilla Flavor, Liquid	RUT-1450	0.09	0.09%	8.2	gram
Bicarbonate of Soda	RUT-901	0.09	0.09%	8.2	gram
Cinnamon	RUT-1508	0.28	0.28%	25.4	gram
Potassium Sorbate	STE-1907	0.10	0.10%	9.1	gram
Guar Gum	RUT-1002	0.10	0.10%	9.1	gram
Xanthan Gum	RUT-1004	0.10	0.10%	9.1	gram
		100	100.0%	20	lbs

Batch Size

Table 16. Percentages of enzyme containing cake formulation

FOOD MANUFACTURING TECHNOLOGY DEMONSTRATION FACILITY

PRODUCTION FORMULA AND INSPECTION PROCEDURES

Revision Date:6/17/08

Supersedes: 12/20/07

Product Name: Devil's Fudge Cake in Polymeric Tray

Material ID: 674-Rutgers- Enzyme

Product Formula:

Description	Mat ID	Recipe	Form %	Quantity	UOM
Water	RUT-90000	29.77	29.77%	2700.5	gram
Sugar, Extra Fine	RUT-201	26.43	26.43%	2397.5	gram
Flour Cake	RUT-103	17.38	17.38%	1576.6	gram
Homecraft		0.00	0.00%	0.0	gram
High Ration Shortening	RUT-315	11.22	11.22%	1017.8	gram
Glycerol	STE-1902	3.17	3.17%	287.6	gram
Cocoa	RUT-614	4.98	4.98%	451.7	gram
Whole Eggs, Dried	STE-401	3.78	3.78%	342.9	gram
Baking Powder, Double Acting	RUT-904	0.76	0.76%	68.9	gram
Salt, Non Iodized	STE-1803	0.73	0.73%	66.2	gram
Starch, Instant, Granular	STE-715	0.99	0.99%	89.8	gram
Vanilla Flavor, Liquid	RUT-1450	0.09	0.09%	8.2	gram
Bicarbonate of Soda	RUT-901	0.15	0.15%	13.6	gram
Cinnamon	RUT-1508	0.28	0.28%	25.4	gram
Potassium Sorbate	STE-1907	0.09	0.09%	8.2	gram
Enzyme (Maxlife)		0.01	0.01%	0.8	gram
Guar Gum	RUT-1002	0.09	0.09%	8.2	gram
Xanthan Gum	RUT-1004	0.09	0.09%	8.2	gram
		100.009	100.0%	20	lbs

Batch Size

Table 17. Percentages of modified flour (homecraft) containing cake formulation

FOOD MANUFACTURING TECHNOLOGY DEMONSTRATION FACILITY

PRODUCTION FORMULA AND INSPECTION PROCEDURES

Revision Date:6/17/08

Supersedes: 12/20/07

Product Name: Devil's Fudge Cake in Polymeric Tray

Material ID: 674-Rutgers-Homecraft

Product Formula:

Sugar, Extra Fine	RUT-201	26.43	26.43%	2397.7	gram
Flour Cake	RUT-103	15.87	15.87%	1439.7	gram
Homecraft		1.51	1.51%	137.0	gram
High Ration Shortening	RUT-315	11.22	11.22%	1017.9	gram
Glycerol	STE-1902	3.17	3.17%	287.6	gram
Cocoa	RUT-614	4.98	4.98%	451.8	gram
Whole Eggs, Dried	STE-401	3.78	3.78%	342.9	gram
Baking Powder, Double Acting	RUT-904	0.76	0.76%	68.9	gram
Salt, Non Iodized	STE-1803	0.73	0.73%	66.2	gram
Starch, Instant, Granular	STE-715	0.99	0.99%	89.8	gram
Vanilla Flavor, Liquid	RUT-1450	0.09	0.09%	8.2	gram
Bicarbonate of Soda	RUT-901	0.15	0.15%	13.6	gram
Cinnamon	RUT-1508	0.28	0.28%	25.4	gram
Potassium Sorbate	STE-1907	0.09	0.09%	8.2	gram
Guar Gum	RUT-1002	0.09	0.09%	8.2	gram
Xanthan Gum	RUT-1004	0.09	0.09%	8.2	gram
		100	100.0%	20	lbs

Batch Size

Table 18. Percentages of high molecular weight gum (locust bean gum) containing cake formulation

FOOD MANUFACTURING TECHNOLOGY DEMONSTRATION FACILITY

PRODUCTION FORMULA AND INSPECTION PROCEDURES

Revision Date:6/17/08

Supersedes: 12/20/07

Product Name: Devil's Fudge Cake in Polymeric Tray

Material ID: 674-Rutgers- LBG

Product Formula:

Description	Mat ID	Recipe	Form %	Quantity	UOM
Water	RUT-90000	29.77	29.77%	2700.7	gram
Sugar, Extra Fine	RUT-201	26.43	26.43%	2397.7	gram
Flour Cake	RUT-103	17.38	17.38%	1576.7	gram
Homecraft		0.00	0.00%	0.0	gram
High Ration Shortening	RUT-315	11.22	11.22%	1017.9	gram
Glycerol	STE-1902	3.17	3.17%	287.6	gram
Cocoa	RUT-614	4.98	4.98%	451.8	gram
Whole Eggs, Dried	STE-401	3.78	3.78%	342.9	gram
Baking Powder, Double Acting	RUT-904	0.76	0.76%	68.9	gram
Salt, Non Iodized	STE-1803	0.73	0.73%	66.2	gram
Starch, Instant, Granular	STE-715	0.99	0.99%	89.8	gram
Vanilla Flavor, Liquid	RUT-1450	0.09	0.09%	8.2	gram
Bicarbonate of Soda	RUT-901	0.15	0.15%	13.6	gram
Cinnamon	RUT-1508	0.28	0.28%	25.4	gram
Potassium Sorbate	STE-1907	0.09	0.09%	8.2	gram
Locust bean gum		0.09	0.09%	8.2	gram
Guar Gum	RUT-1002	0.09	0.09%	8.2	gram
Xanthan Gum	RUT-1004	0.00	0.00%	0.0	gram
		100	100.0%	20	lbs

Batch Size

Table 19. Percentages of emulsifier containing cake

FOOD MANUFACTURING TECHNOLOGY DEMONSTRATION FACILITY

PRODUCTION FORMULA AND INSPECTION PROCEDURES

Revision Date:6/17/08

Supersedes: 12/20/07

Product Name: Devil's Fudge Cake in Polymeric Tray

Material ID: 674-Rutgers- Emulsifier

<u>Product Formula:</u>

Description	Mat ID	Recipe	Form %	Quantity	UOM
Water	RUT-90000	29.77	29.77%	2700.7	gram
Sugar, Extra Fine	RUT-201	25.99	25.99%	2357.8	gram
Flour Cake	RUT-103	17.38	17.38%	1576.7	gram
Homecraft		0.00	0.00%	0.0	gram
High Ration Shortening	RUT-315	10.90	10.90%	988.8	gram
Glycerol	STE-1902	3.17	3.17%	287.6	gram
Cocoa	RUT-614	4.98	4.98%	451.8	gram
Whole Eggs, Dried	STE-401	3.78	3.78%	342.9	gram
Baking Powder, Double Acting	RUT-904	0.76	0.76%	68.9	gram
Salt, Non Iodized	STE-1803	0.73	0.73%	66.2	gram
Starch, Instant, Granular	STE-715	0.99	0.99%	89.8	gram
Vanilla Flavor, Liquid	RUT-1450	0.09	0.09%	8.2	gram
Bicarbonate of Soda	RUT-901	0.15	0.15%	13.6	gram
Cinnamon	RUT-1508	0.28	0.28%	25.4	gram
Potassium Sorbate	STE-1907	0.09	0.09%	8.2	gram
Emulsifier		0.76	0.76%	68.9	gram
Guar Gum	RUT-1002	0.09	0.09%	8.2	gram
Xanthan Gum	RUT-1004	0.09	0.09%	8.2	gram
		100	100.0%	20	lbs
Batch Size					

Table 20. Percentages of polydextrose containing cake formulation

FOOD MANUFACTURING TECHNOLOGY DEMONSTRATION FACILITY

PRODUCTION FORMULA AND INSPECTION PROCEDURES

Revision Date:6/17/08

Supersedes: 12/20/07

Product Name: Devil’s Fudge Cake in Polymeric Tray

Material ID: 674-Rutgers-Polydextrose

Product Formula:

Description	Mat ID	Recipe	Form %	Quantity	UOM
Water	RUT-90000	29.77	29.77%	2700.7	gram
Sugar, Extra Fine	RUT-201	26.12	26.12%	2369.6	gram
Flour Cake	RUT-103	17.38	17.38%	1576.7	gram
Homecraft		0.00	0.00%	0.0	gram
High Ration Shortening	RUT-315	11.22	11.22%	1017.9	gram
Glycerol	STE-1902	3.17	3.17%	287.6	gram
Cocoa	RUT-614	4.98	4.98%	451.8	gram
Whole Eggs, Dried	STE-401	3.78	3.78%	342.9	gram
Baking Powder, Double Acting	RUT-904	0.76	0.76%	68.9	gram
Salt, Non Iodized	STE-1803	0.73	0.73%	66.2	gram
Starch, Instant, Granular	STE-715	0.99	0.99%	89.8	gram
Vanilla Flavor, Liquid	RUT-1450	0.09	0.09%	8.2	gram
Bicarbonate of Soda	RUT-901	0.15	0.15%	13.6	gram
Cinnamon	RUT-1508	0.28	0.28%	25.4	gram
Potassium Sorbate	STE-1907	0.09	0.09%	8.2	gram
Polydextrose		0.31	0.31%	28.1	
Guar Gum	RUT-1002	0.09	0.09%	8.2	gram
Xanthan Gum	RUT-1004	0.09	0.09%	8.2	gram
		100	100.0%	20	lbs

Batch Size

Table 21. Percentages of polydextrose and emulsifier containing cake formulation

FOOD MANUFACTURING TECHNOLOGY DEMONSTRATION FACILITY

PRODUCTION FORMULA AND INSPECTION PROCEDURES

Revision Date:6/17/08

Supersedes: 12/20/07

Product Name: Devil's Fudge Cake in Polymeric Tray

Material ID: 674-Rutgers- PDE

Product Formula:

Description	Mat ID	Recipe	Form %	Quantity	UOM
Water	RUT-90000	29.77	29.77%	2701.0	gram
Sugar, Extra Fine	RUT-201	25.99	25.99%	2358.0	gram
Flour Cake	RUT-103	17.38	17.38%	1576.9	gram
Homecraft		0.00	0.00%	0.0	gram
High Ration Shortening	RUT-315	10.90	10.90%	988.9	gram
Glycerol	STE-1902	3.17	3.17%	287.6	gram
Cocoa	RUT-614	4.98	4.98%	451.8	gram
Whole Eggs, Dried	STE-401	3.78	3.78%	343.0	gram
Baking Powder, Double Acting	RUT-904	0.76	0.76%	69.0	gram
Salt, Non Iodized	STE-1803	0.73	0.73%	66.2	gram
Starch, Instant, Granular	STE-715	0.99	0.99%	89.8	gram
Vanilla Flavor, Liquid	RUT-1450	0.09	0.09%	8.2	gram
Bicarbonate of Soda	RUT-901	0.15	0.15%	13.6	gram
Cinnamon	RUT-1508	0.28	0.28%	25.4	gram
Potassium Sorbate	STE-1907	0.09	0.09%	8.2	gram
Polydextrose		0.25	0.25%	22.7	gram
Emulsifier		0.50	0.50%	45.4	gram
Guar Gum	RUT-1002	0.09	0.09%	8.2	gram
Xanthan Gum	RUT-1004	0.09	0.09%	8.2	gram
		99.99	100.0%	20	lbs

Table 22. Percentages of surfactant (polysorbate 60) containing cake formulation

FOOD MANUFACTURING TECHNOLOGY DEMONSTRATION FACILITY

PRODUCTION FORMULA AND INSPECTION PROCEDURES

Revision Date:6/17/08

Supersedes: 12/20/07

Product Name: Devil's Fudge Cake in Polymeric Tray

Material ID: 674-Rutgers-PS60

Product Formula:

Description	Mat ID	Recipe	Form %	Quantity	UOM
Water	RUT-90000	29.77	29.77%	2700.7	gram
Sugar, Extra Fine	RUT-201	26.00	26.00%	2358.7	gram
Flour Cake	RUT-103	17.38	17.38%	1576.7	gram
Homecraft		0.00	0.00%	0.0	gram
High Ration Shortening	RUT-315	11.22	11.22%	1017.9	gram
Glycerol	STE-1902	3.17	3.17%	287.6	gram
Cocoa	RUT-614	4.98	4.98%	451.8	gram
Whole Eggs, Dried	STE-401	3.78	3.78%	342.9	gram
Baking Powder, Double Acting	RUT-904	0.76	0.76%	68.9	gram
Salt, Non Iodized	STE-1803	0.73	0.73%	66.2	gram
Starch, Instant, Granular	STE-715	0.99	0.99%	89.8	gram
Vanilla Flavor, Liquid	RUT-1450	0.09	0.09%	8.2	gram
Bicarbonate of Soda	RUT-901	0.15	0.15%	13.6	gram
Cinnamon	RUT-1508	0.28	0.28%	25.4	gram
Potassium Sorbate	STE-1907	0.09	0.09%	8.2	gram
PS60		0.43	0.43%	39.0	gram
Guar Gum	RUT-1002	0.09	0.09%	8.2	gram
Xanthan Gum	RUT-1004	0.09	0.09%	8.2	gram
		100	100.0%	20	lbs

Batch Size

Table 23. Percentages of combination of ingredients (#1) cake formulation

FOOD MANUFACTURING TECHNOLOGY DEMONSTRATION FACILITY

PRODUCTION FORMULA AND INSPECTION PROCEDURES

Revision Date: 3/3/08

Supersedes: 12/20/07

Product Name: Devil's Fudge Cake in Polymeric Tray

Material ID: 674-Rutgers-Combo#1

Product Formula:

Description	Mat ID	Recipe	Form %	Quantity	UOM
Water	RUT-90000	29.76	29.76%	2699.8	gram
Sugar, Extra Fine	RUT-201	26.00	26.00%	2358.7	gram
Flour Cake	RUT-103	15.87	15.87%	1439.7	gram
Homecraft Flour	RUT-676	1.51	1.51%	137.0	gram
High Ration Shortening	RUT-315	11.22	11.22%	1017.9	gram
Glycerol	STE-1902	3.17	3.17%	287.6	gram
Cocoa	RUT-614	4.98	4.98%	451.8	gram
Whole Eggs, Dried	STE-401	3.78	3.78%	342.9	gram
Baking Powder, Double Acting	RUT-904	0.75	0.75%	68.0	gram
Salt, Non Iodized	STE-1803	0.72	0.72%	65.3	gram
Starch, Instant, Granular	STE-715	0.99	0.99%	89.8	gram
Vanilla Flavor, Liquid	RUT-1450	0.09	0.09%	8.2	gram
Bicarbonate of Soda	RUT-901	0.15	0.15%	13.6	gram
Cinnamon	RUT-1508	0.28	0.28%	25.4	gram
Potassium Sorbate	STE-1907	0.09	0.09%	8.2	gram
Polysorbate60	RUT-678	0.45	0.45%	40.8	gram
Maxlife	RUT-677	0.01	0.01%	0.9	gram
Guar Gum	RUT-1002	0.09	0.09%	8.2	gram
Xanthan Gum	RUT-1004	0.09	0.09%	8.2	gram
		100	100.0%	20	lbs

Table 24. Percentages of combination of ingredients (#2) cake formulation

FOOD MANUFACTURING TECHNOLOGY DEMONSTRATION FACILITY

PRODUCTION FORMULA AND INSPECTION PROCEDURES

Revision Date: 3/3/08

Supersedes: 12/20/07

Product Name: Devil's Fudge Cake in Polymeric Tray

Material ID: 674-Rutgers-Combo#2

Product Formula:

Description	Mat ID	Recipe	Form %	Quantity	UOM
Water	RUT-90000	29.920	29.84%	2707.1	gram
Sugar, Extra Fine	RUT-201	25.350	25.28%	2293.6	gram
Flour Cake	RUT-103	15.950	15.91%	1443.1	gram
Homecraft Flour	RUT-676	0.760	0.76%	68.8	gram
High Ration Shortening	RUT-315	11.390	11.36%	1030.5	gram
Glycerol	STE-1902	3.189	3.18%	288.5	gram
Cocoa	RUT-614	5.000	4.99%	452.4	gram
Whole Eggs, Dried	STE-401	3.800	3.79%	343.8	gram
Baking Powder, Double Acting	RUT-904	0.760	0.76%	68.8	gram
Salt, Non Iodized	STE-1803	0.730	0.73%	66.0	gram
Starch, Instant, Granular	STE-715	1.000	1.00%	90.5	gram
Vanilla Flavor, Liquid	RUT-1450	0.090	0.09%	8.1	gram
Bicarbonate of Soda	RUT-901	0.150	0.15%	13.6	gram
Cinnamon	RUT-1508	0.280	0.28%	25.3	gram
Potassium Sorbate	STE-1907	0.098	0.10%	8.9	gram
Polysorbate60	RUT-678	0.460	0.46%	41.6	gram
Maxlife	RUT-677	0.006	0.01%	0.5	gram
Poly dextrose	RUT-680	0.380	0.38%	34.4	gram
Emulsifier	RUT-681	0.760	0.76%	68.8	gram
Guar Gum	RUT-1002	0.098	0.10%	8.9	gram
Locust Beam Gum	RUT-682	0.098	0.10%	8.9	gram
		100.269	100.0%	20	lbs

5.4 Long term shelf life testing protocol for cakes produced at FMT

The following shelf life plan was done for the cake samples. Control, emulsifier agent, enzyme, pregelatinized starch, polydextrose containing and combination of all the ingredients were analyzed in terms of shelf life study by the following outline (Figure 14).

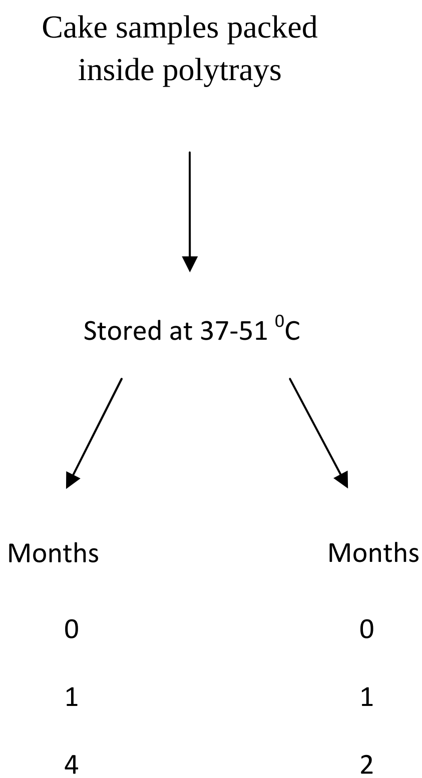


Figure 14. Shelf life protocol for cake samples

The cake samples were tested in terms of overall quality and shelf life by the following criteria:

1. Textural stability (Uniaxial compression testing)
2. Physical stability (volume, cell size)
3. Thermal stability (glass transition temperature, retrogradation enthalpy, crystallization)

Staling reactions in starch based products results in changes in both texture and flavor. Cake can be defined as a system which is unstable, elastic, solid foam. Starch retrogradation can be

encountered as a key factor contributing to staling. It depends on several factors such as moisture migration/redistribution and the glassy-rubbery state of polymers. The gelatinized starch granules reassociate during aging which is followed by a gradual increase in firming. Recrystallization of amylopectin granules during long term storage increases the rigidity of the product in time. The rate of retrogradation can be studied by various physicochemical methods. The increase in enthalpy change (by Differential Scanning Calorimeter), firmness (by Texture Analyzer), loss in flavor, moisture content, water activity, X-Ray diffraction and starch solubility have mostly been used by researchers to follow up the starch retrogradation rate.

5.4.1 Textural evaluation of cakes

The shelf life study results of cake samples which were baked and packed according to the PCR-C-024A specification in polymeric trays with oxygen scavenger at FMT facilities and then put to storage boxes of 37 ^{0}C (1month and 4 months) and 50 ^{0}C (1month and 2 months) are presented in Tables 25 and 26. The hardness and toughness values of cake samples were generally higher for the cakes which were stored at 37 ^{0}C (Figure 15, Figure 16). The hardness and toughness values of cake samples which were stored at 50 ^{0}C slightly increased from month 1 to month 2 (Figure 17, Figure 18). The springiness values which are associated with the elastic recovery of the cake samples did not vary too much by increased storage time (Figure 19, Figure 20). The staling rates of cake samples were previously found to be higher for storage temperatures around 25 ^{0}C due to higher amounts of starch and plasticizers in the formulation. Combination 1 formulation had the lowest toughness and hardness values for storage temperature at 50 ^{0}C whereas the polysorbate 60 cake had the lowest values for storage temperature 37 ^{0}C. In both storage conditions the changes in both water activities and percent moisture content values were negligible (Table 27).

Table 25. Textural parameters of cake samples stored at 37 ^{0}C

	Cake samples	Hardness (N)	Springness	Toughness (Ns)	Rupture distance (mm)	Gradient
37 ^{0}C 1 month	Control	11.40±0.60	46.41±0.92	62.39±5.71	9.61±0.14	1.49±0.26
	Homecraft	12.09±0.41	44.23±0.25	67.48±3.45	9.80±0.43	1.48±0.15
	Polydextrose	11.69±1.01	44.31±0.47	69.86±4.08	9.83±0.19	1.35±0.19
	PS60	8.23±0.39	44.78±0.92	44.66±5.14	9.64±0.24	1.08±0.18
	Emulsifier	10.08±0.33	45.58±1.36	59.68±5.61	9.77±0.32	1.29±0.31
	Locust bean gum	11.83±0.94	46.35±0.63	64.42±4.62	9.98±0.38	1.37±0.17
	Polydextrose+Emulsifier	10.14±0.69	44.92±0.55	53.33±3.72	9.65±0.07	1.25±0.21
	Enzyme	10.31±0.64	44.38±0.58	53.33±3.72	9.65±0.07	1.25±0.21
	Combo1	8.55±0.38	45.34±0.98	45.72±3.84	9.61±0.39	0.98±0.14
	Combo2	7.11±0.98	45.05±0.90	34.23±8.14	10.13±0.52	0.84±0.19
37 ^{0}C 4 months	**Cake samples**	**Hardness (N)**	**Springness**	**Toughness (Ns)**	**Rupture distance (mm)**	**Gradient**
	Control	11.28±0.57	44.62±0.61	67.63±5.89	9.90±0.21	0.92±0.12
	Homecraft	11.71±0.24	41.65±0.39	70.01±2.59	9.54±0.14	0.81±0.12
	Polydextrose	12.36±0.44	42.35±0.32	74.39±2.47	9.65±0.27	0.89±0.13
	PS60	9.05±1.25	44.24±0.80	52.90±6.99	9.73±0.17	0.68±0.15
	Emulsifier	9.92±0.59	43.05±0.65	54.62±5.73	9.66±0.26	0.90±0.16
	Locust bean gum	10.99±0.83	44.97±0.28	60.02±7.22	9.76±0.18	1.00±0.07
	Polydextrose+Emulsifier	10.15±0.38	42.75±0.59	60.47±5.85	10.02±0.15	0.89±0.27
	Enzyme	10.34±0.83	42.12±0.45	62.59±5.96	9.93±0.12	0.83±0.18
	Combo1	10.23±1.06	43.72±0.44	56.23±5.99	9.74±0.27	0.88±0.14
	Combo2	10.24±0.99	44.33±0.50	46.77±3.01	9.56±0.07	1.19±0.29

Table 26. Textural parameters of cake samples stored at 50 ^{0}C

	Cake samples	Hardness (N)	Springness	Toughness (Ns)	Rupture distance (mm)	Gradient
50 ^{0}C 1 month	Control	10.66±0.81	46.01±1.22	56.34±7.93	9.87±0.41	1.54±0.23
	Homecraft	11.39±1.35	43.09±1.46	64.38±2.71	10.15±0.47	1.45±0.54
	Polydextrose	12.24±0.54	44.09±0.62	63.07±4.08	9.57±0.26	1.29±0.13
	PS60	11.16±0.90	44.48±0.65	62.15±7.54	9.57±0.26	1.29±0.13
	Emulsifier	12.73±1.19	44.52±0.74	72.11±4.65	9.79±0.24	1.51±0.28
	Locust bean gum	12.45±1.22	45.16±0.72	67.61±11.96	10.07±0.23	1.43±0.19
	Polydextrose+Emulsifier	9.81±0.68	43.64±1.03	53.96±4.85	9.57±0.34	1.24±0.06
	Enzyme	10.12±0.78	43.66±1.03	56.44±4.03	9.76±0.41	1.21±0.15
	Combo1	8.86±1.08	45.53±0.75	44.51±7.58	9.78±0.45	1.18±0.14
	Combo2	10.85±1.58	44.81±1.41	50.69±7.38	9.43±0.33	1.34±0.20
50 ^{0}C 2 months	**Cake samples**	**Hardness (N)**	**Springness**	**Toughness (Ns)**	**Rupture distance (mm)**	**Gradient**
	Control	12.04±0.41	43.48±0.59	71.41±2.49	10.03±0.11	1.69±0.13
	Homecraft	13.74±0.73	42.68±0.22	76.11±7.21	9.48±0.40	1.84±0.22
	Polydextrose	13.29±0.88	42.96±0.95	77.00±8.14	9.84±0.29	1.65±0.28
	PS60	11.05±0.96	44.29±0.83	65.03±5.90	10.03±0.36	1.25±0.24
	Emulsifier	12.66±0.80	43.25±1.10	71.81±8.26	9.72±0.32	1.53±0.50
	Locust bean gum	10.72±0.62	45.58±0.96	52.87±4.88	9.89±0.46	1.45±0.33
	Polydextrose+Emulsifier	10.91±0.49	43.07±0.35	61.04±10.08	9.65±0.94	1.29±0.11
	Enzyme	10.47±1.00	42.65±1.70	61.87±6.87	10.23±0.73	1.24±0.48
	Combo1	9.34±0.80	43.72±0.55	51.68±5.46	9.95±0.44	1.19±0.12
	Combo2	14.51±1.49	43.53±0.56	60.51±9.23	9.01±0.42	1.98±0.21

Table 27. Water activities and percent moisture contents of cake samples stored at 37 and 50 ^{0}C

Cake samples	**50 ^{0}C 1month % MC**	**50 ^{0}C 1month aw**	**50 ^{0}C 2 months %MC**	**50 ^{0}C 2 months aw**
Control	25.24	0.841	24.17	0.832
Homecraft	24.41	0.833	23.90	0.828
Polydextrose	25.03	0.850	24.11	0.832
PS60	25.16	0.841	23.90	0.828
Emulsifier	25.29	0.845	24.90	0.837
Locust bean gum	24.61	0.838	23.61	0.825
Polydextrose+Emulsifier	24.73	0.835	24.18	0.828
Enzyme	24.34	0.830	23.97	0.827
Combo1	25.78	0.837	24.37	0.832
Combo2	24.20	0.848	24.72	0.837
Cake samples	**37 ^{0}C 1month % MC**	**37 ^{0}C 1month aw**	**37 ^{0}C 4 months %MC**	**37 ^{0}C 4 months Aw**
Control	25.12	0.846	25.05	0.829
Homecraft	25.28	0.841	24.47	0.822
Polydextrose	25.54	0.846	24.59	0.827
PS60	25.17	0.843	24.22	0.830
Emulsifier	24.98	0.845	24.40	0.829
Locust bean gum	24.75	0.840	23.37	0.821
Polydextrose+Emulsifier	25.23	0.839	24.49	0.827
Enzyme	23.92	0.843	24.87	0.825
Combo1	24.88	0.847	24.27	0.831
Combo2	24.15	0.831	24.21	0.829

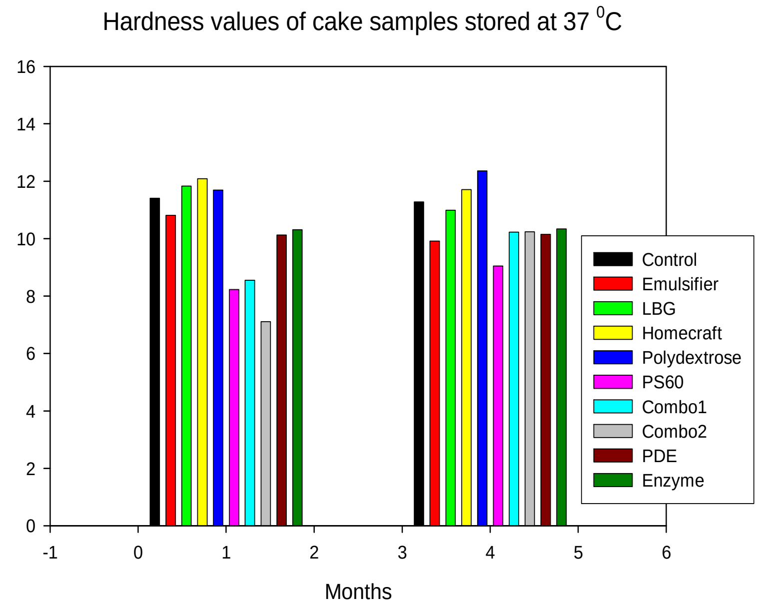


Figure 15. Hardness values of cake samples stored at 37 ^{0}C

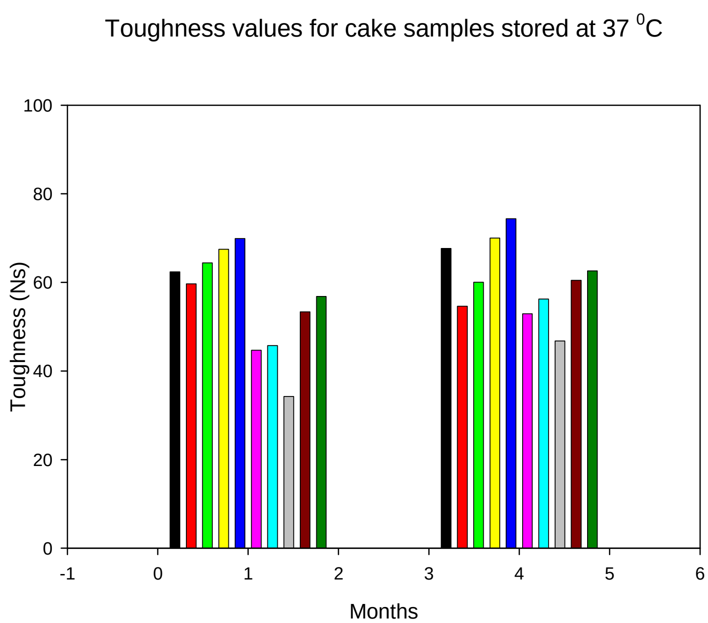


Figure 16. Toughness values of cake samples stored at 37 ^{0}C

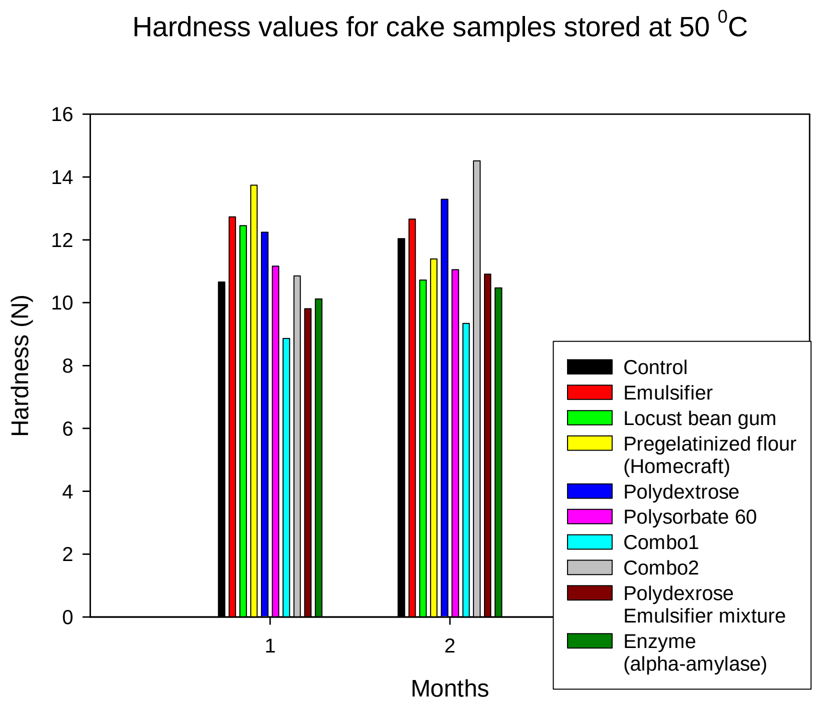


Figure 17. Hardness values of cake samples stored at 50 ^{0}C

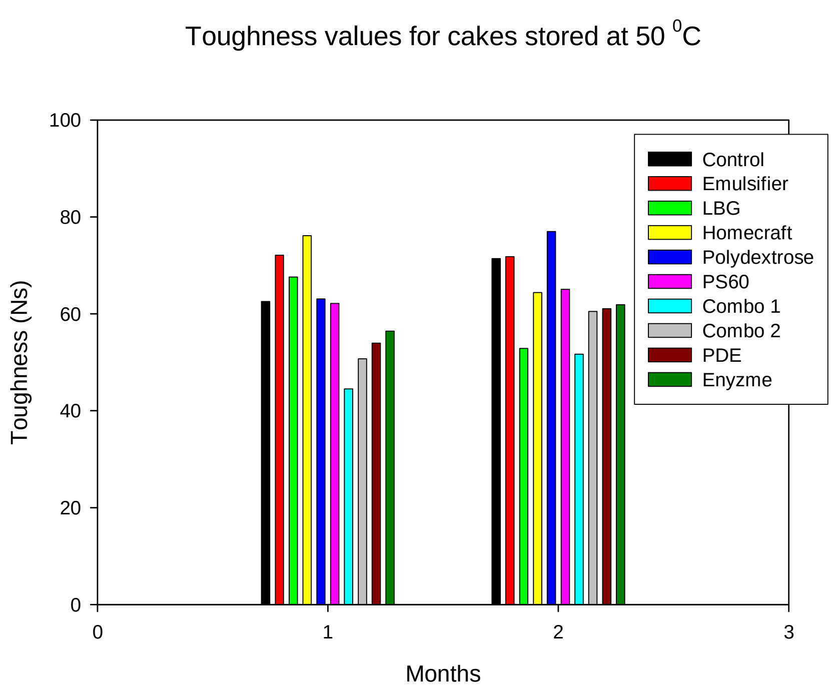


Figure 18. Toughness values of cake samples stored at 50 ^{0}C

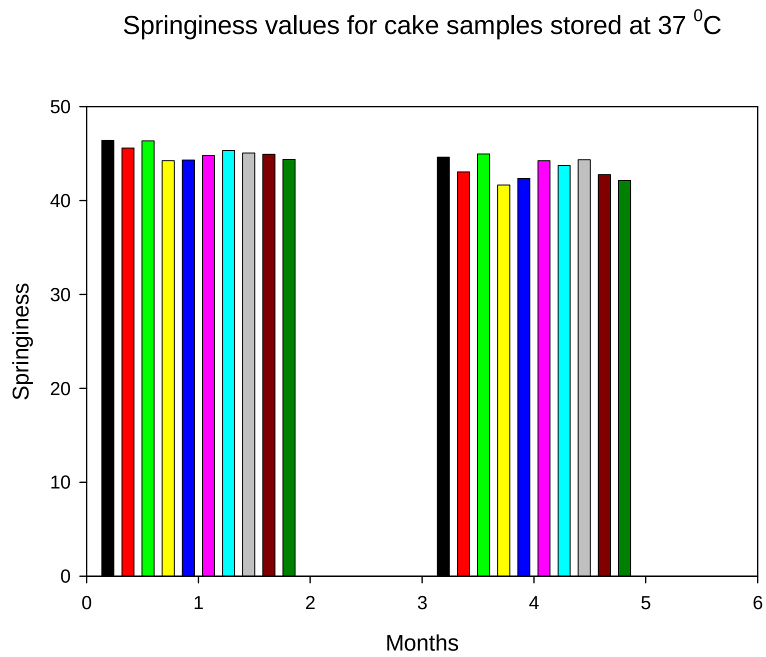


Figure 19. Springiness values of cake samples stored at 37 ^{0}C

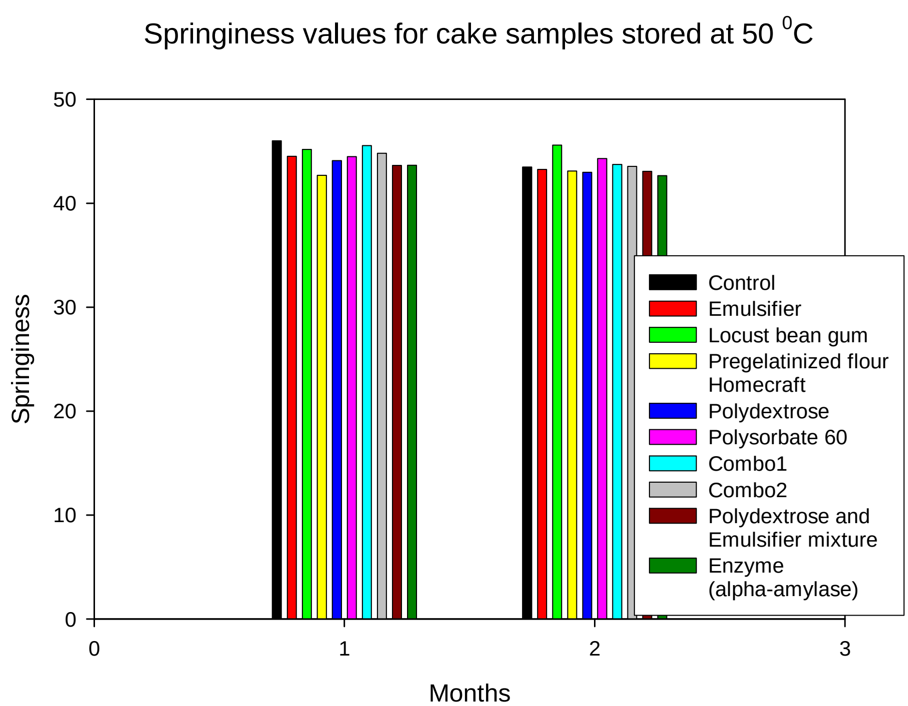


Figure 20. Springiness values of cake samples stored at 50 ^{0}C

5.4.2 Thermal characterization of cakes

Starch granule consists of concentric layers which contain crystalline micelles showing different refraction patterns. The pattern type is dependent on percent moisture content. Samples which contain more than 43% moisture develops B pattern during aging whereas the ones containing less than 29 % moisture yields A patterns. At the intermediate moisture levels C type pattern can be obtained which is a combination of A and B patterns. Starch retrogradation can be characterized by a B type pattern. Starch crystalline level was determined by wide angle X-ray diffraction. For the peak identification, the position of known starch phases was used. Four peaks at d spacing of 5.9, 5.2, 4.0 and 3.7 A^0 (corresponding to 2θ angles of 15.0, 17.0, 22.2 and 24.0^0, respectively) were analyzed by B-type crystalline phase identification. Only one peak was detectable using the V-type crystalline phase identification (d spacing of 4.3–4.4 A^0 corresponding to 2 θ angle 20.0^0). One peak at 4.4 A^0 often appears as a first indication of V-complex formation. In our cakes we observed both B-type and V-type crystalline phases corresponding to 2θ angle at 20 and 24^0 , respectively.

Storage of cake samples at 50 ^{0}C for 2 months (Figure 21) resulted in more crystalline structure as compared to the cake samples which were stored at 37 ^{0}C for 4 months. The emulsifier, combination 2, polydextrose and emulsifier mixture showed the least crystalline structures when they are stored for 2 months at 50 ^{0}C whereas the combination 2 and emulsifier containing formulations had less starch crystals for a storage period of 4 months at 37 ^{0}C (Figure 22).

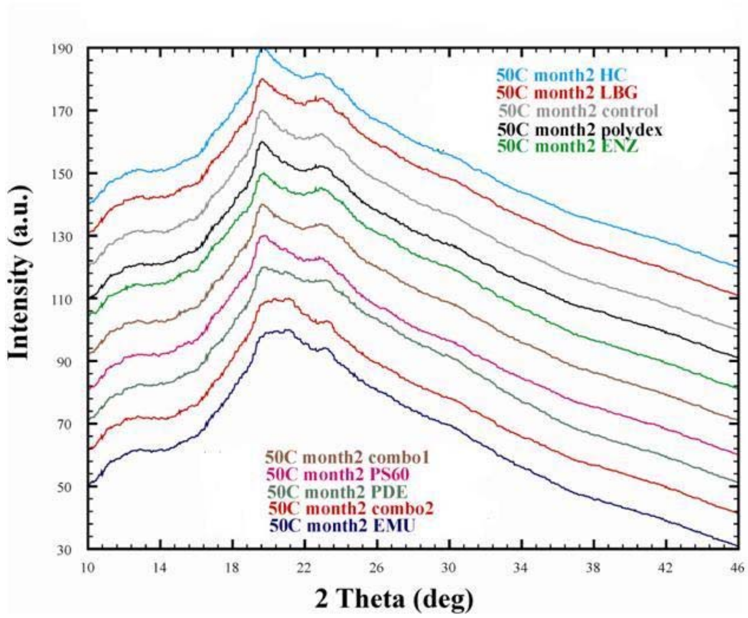


Figure 21. X-ray diffraction analysis of cake samples stored at 50 ^{0}C for 2 months

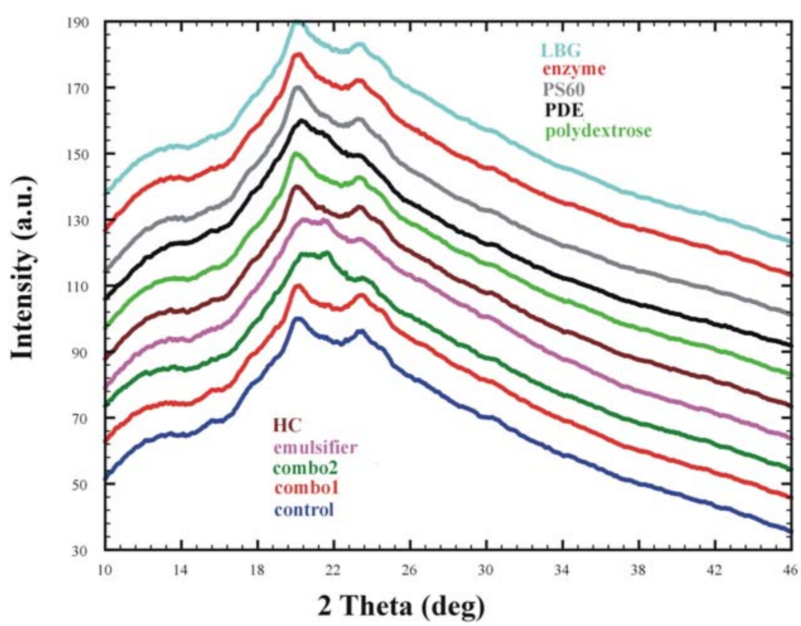


Figure 22. X-ray diffraction analysis of cake samples stored at 37 ^{0}C for 4 months

Differential scanning calorimeter technique was used to evaluate the retrogradation peaks which were developed during storage of cake samples (Figure 23). The onset, midpoint and end point temperatures of the peaks were calculated. The area under the curve gave the enthalpy values. All the enthalpy values were based on dry matter content.

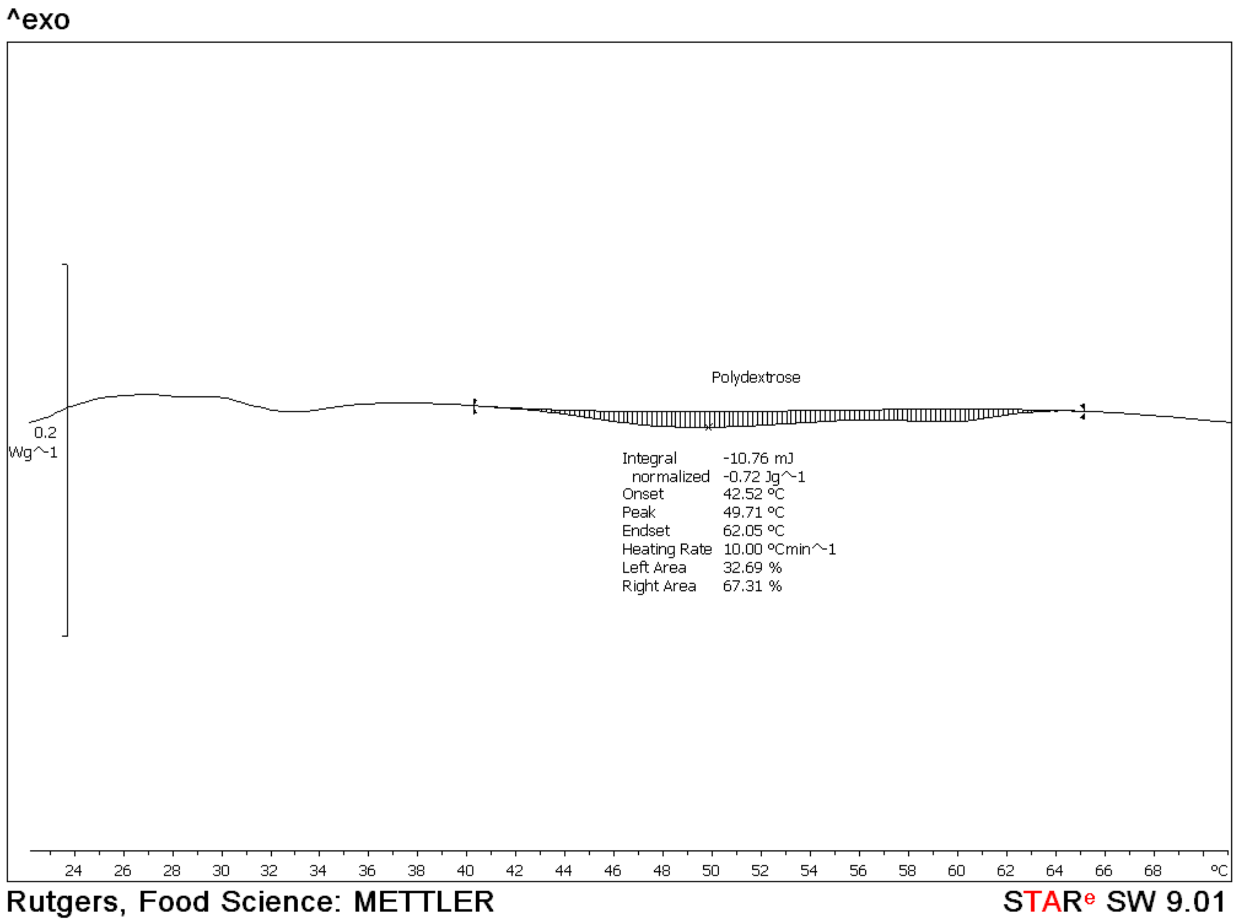


Figure 23. Calculation technique of starch retrogradation peaks obtained from differential scanning calorimeter

The retrogradation peak temperatures were around 52 ^{0}C. The enthalpy values of the retrograded starch are an indicator of the melting of crystallites which were formed during storage. The enthalpy values decreased as the amount crystalline starch fraction decreased. Enthalpy values of formulations Combo 1, enzyme, polydextrose and emulsifier mixture gave the lowest scores after 4 months of storage at 37 ^{0}C leading to slowest starch retrogradation rate (Table 28). Long term storage at 50 ^{0}C for 2 months resulted in enthalpy values close to 37 ^{0}C for 4 months (Table 29). This showed us that storage at higher temperatures accelerated starch retrogradation.

Table 28. Thermal parameters of cake samples stored at 37 ^{0}C for 4 months

Cake samples	**Tonset (^{0}C)**	**Tpeak (^{0}C)**	**Tend (^{0}C)**	**Enthalpy (J/g)**
Control	42.57	49.20	60.16	1.23
Combo 1	48.37	46.38	60.74	0.30
Combo 2	41.77	51.10	62.99	0.91
Homecraft flour (HC)	40.21	48.68	56.34	0.96
Enyzme (α-amylase)	47.81	51.35	63.75	0.58
Polydextrose+Emulsifier mixture	48.67	52.26	61.66	0.61
Emulsifier	40.63	56.21	61.85	0.94
Polysorbate 60	41.76	47.54	59.15	0.62
Locust bean gum	41.17	49.53	58.29	0.81
Polydextrose	42.52	49.71	62.05	0.72

Table 29. Thermal parameters of cake samples stored at 50 ^{0}C for 2 months

Cake samples	**Tonset (^{0}C)**	**Tpeak (^{0}C)**	**Tend (^{0}C)**	**Enthalpy (J/g)**
Control	45.12	48.52	59.06	1.37
Combo 1	47.03	48.08	61.07	0.28
Combo 2	42.19	53.09	60.97	0.98
Homecraft flour (HC)	43.15	49.67	58.19	0.88
Enyzme (α-amylase)	46.59	52.13	61.75	0.61
Polydextrose+Emulsifier mixture	47.23	50.77	60.36	0.59
Emulsifier	42.15	55.02	60.89	1.02
PS60	40.93	45.99	60.78	0.68
Locust bean gum	42.02	50.39	59.68	0.77
Polydextrose	44.56	50.37	61.02	0.67

5.5 Accelerated shelf life testing protocol for cakes produced at FMT

Cakes are food systems where the final structure is a mixture of protein foam and starch network. A good quality cake should be high in volume and with fine relatively uniform crumb structure. Ingredients such as enzymes, gums and plasticizers could be used to extend the period of freshness by retarding the rate of staling. The cakes which were baked and sealed inside polymeric trays at FMT facilities were grouped in four sets of control, Combo 1 and Combo 2. The cakes were at first stored at 37 and 50 ^{0}C for 1 month and then transferred to storage boxes

at 4 and 25 ^{0}C for 1 week. Each set of sample were tested for texture, moisture content, water activity, starch crystallinity and thermal properties.

5.5.1 Evaluation of textural parameters

Table 30 and 31 shows textural parameters of cake samples. The initial hardness and toughness values of control sample were higher than both of the combination formulations whereas springiness value was the lowest. Both combination formulations showed better textural parameters (low hardness and toughness, high springiness values) compared to the control cake. The combination formulations were more elastic and the crumbs were softer. The cake samples which were stored at 50 ^{0}C for 1 month had higher hardness and toughness values than the samples stored at 37 ^{0}C (Figure 24-25). Combination cakes had lower hardness values than the control cake. Storage at 50 ^{0}C was found to accelerate the staling rate. In general toughness of combination 2 cake was the lowest at each storage conditions (Figure 26-27). Cooling of cakes from 37 and 50 ^{0}C to lower temperatures of 4 and 25 ^{0}C caused changes on the textural values. The differences between the hardness and toughness values for the initial and refrigerated cakes were highest after storage at 50 ^{0}C for 1 month. Both water activity and moisture content values did not change much with different storage protocols that we tested. The water activities for the samples were approximately 0.84 whereas the moisture contents were around 25 % (Table 32). The ANOVA table decomposes the variability of toughness due to temperature and ingredient factors. The P-values tested the statistical significance of each two factors. The P-values were less than 0.05 which indicated statistically significant effect of temperature and ingredient factors on toughness value at the 95% confidence level (Tables 33 and 34). The toughness values were found to be homogenously different for control, combo 1 and combo 2 cake samples stored at 37 ^{0}C. However, for cakes stored at 50 ^{0}C combo 1 and combo 2 formulations were within the same homogenous group. Cycling to lower temperatures significantly altered the toughness values (Tables 35 and 36).

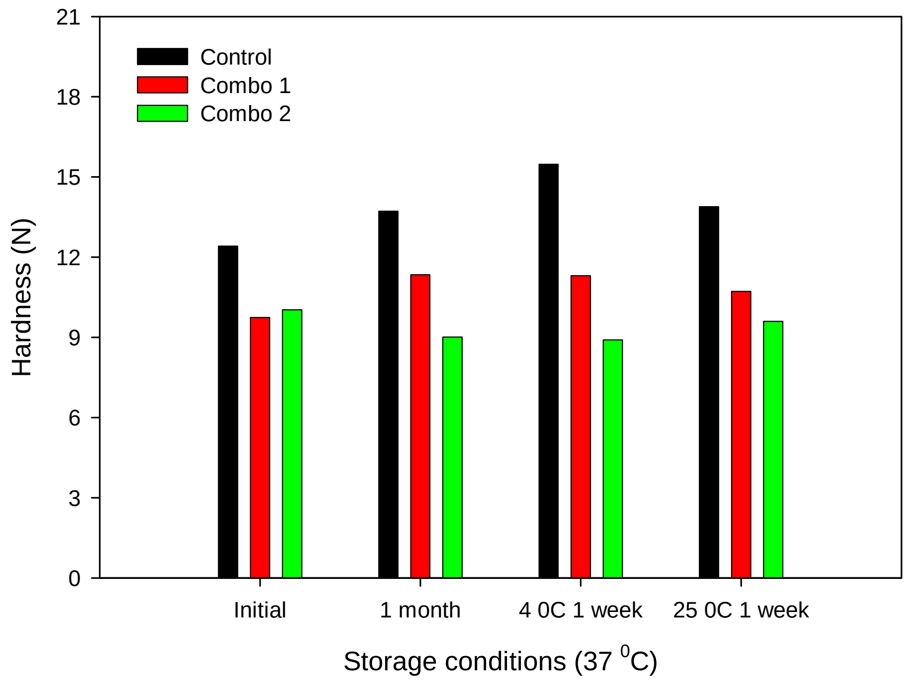


Figure 24. Hardness values of cakes stored at 37 ^{0}C for one month

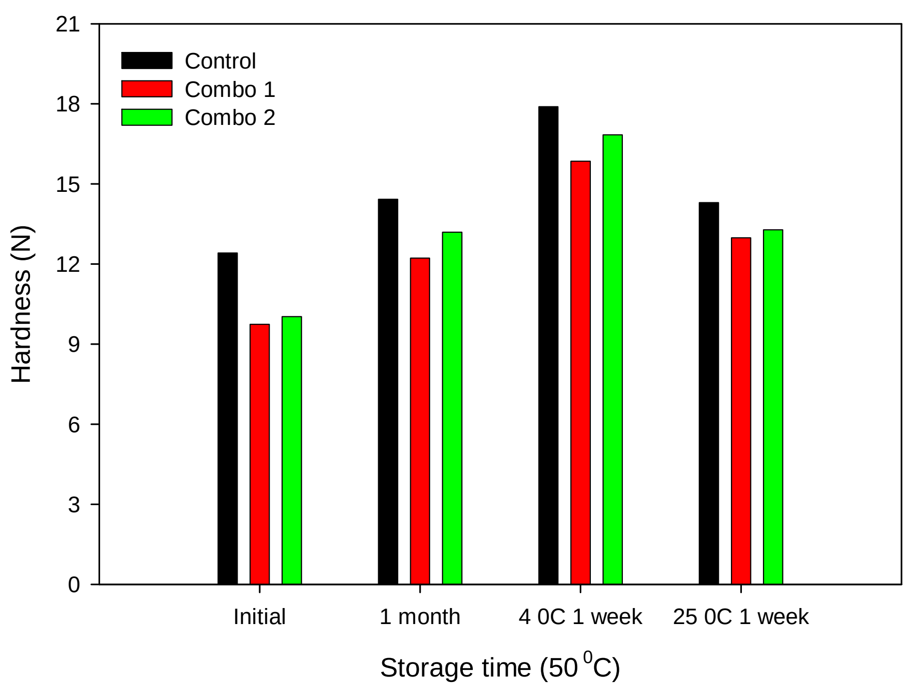


Figure 25. Hardness values of cakes stored at 50 ^{0}C for one month

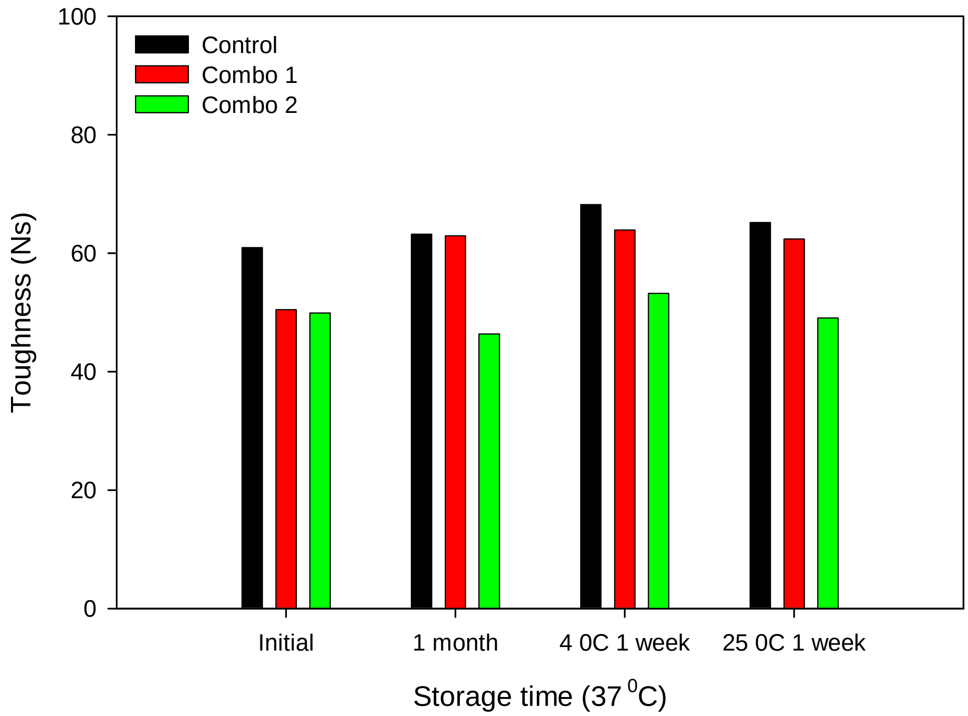


Figure 26. Toughness values of cakes stored at 37 ^{0}C for one month

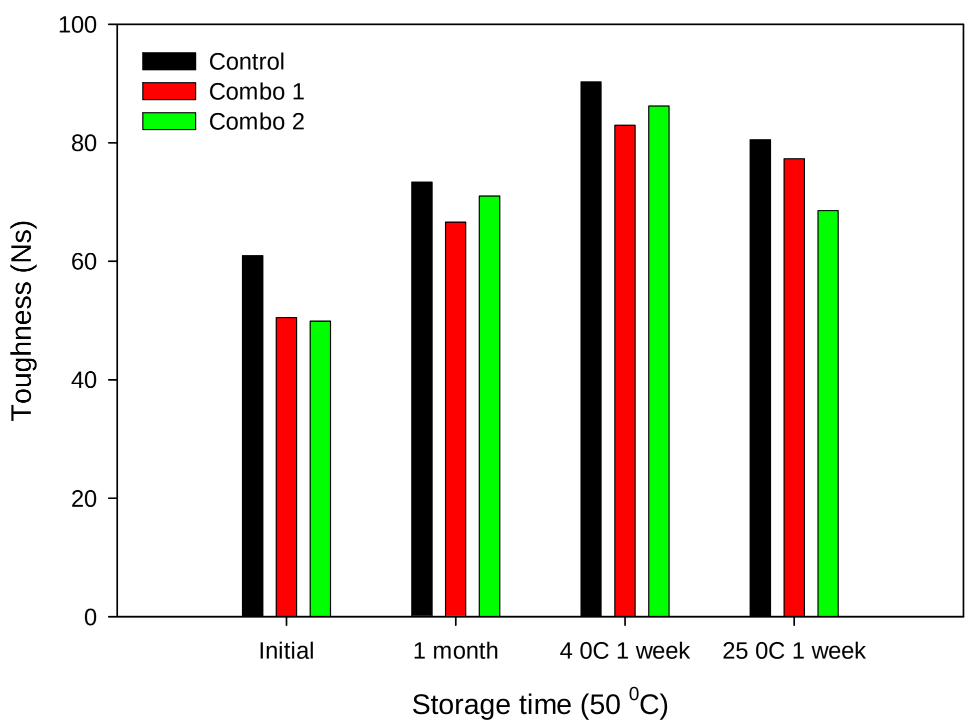


Figure 27. Toughness values of cakes stored at 50 ^{0}C for one month

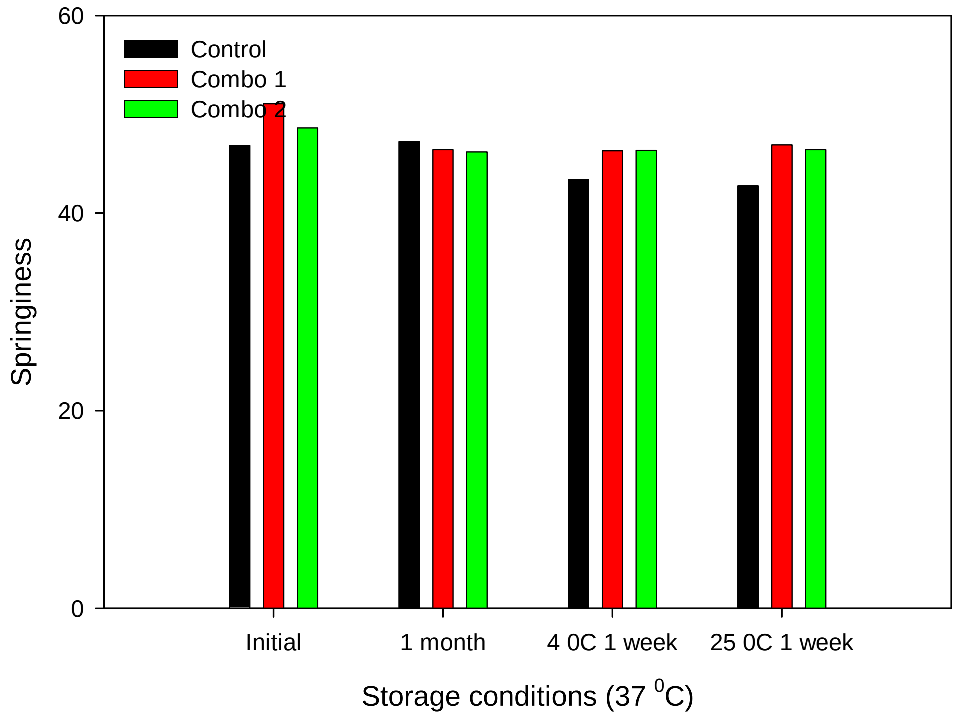


Figure 28. Springiness values of cakes stored at 37 ^{0}C for one month

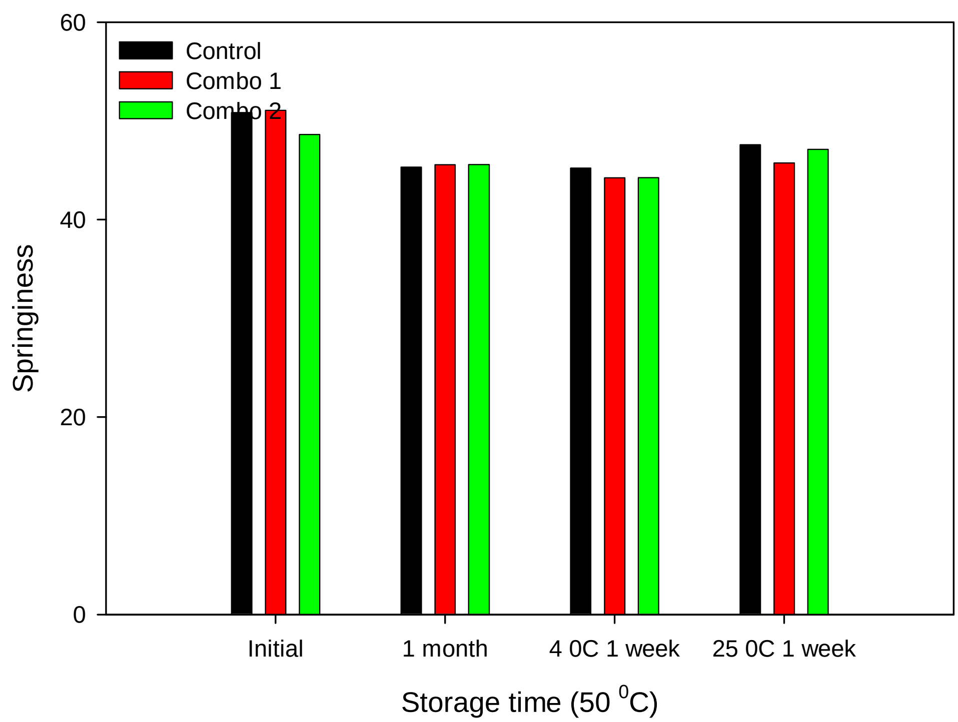


Figure 29. Springiness values of cakes stored at 50 ^{0}C for one month

Table 30.Textural parameters of cake samples stored at 37 ^{0}C

Storage conditions	**Cake type**	**Hardness (N)**	**Springiness**	**Toughness (N.s)**	**Gradient**
Initial	Control	**12.41±0.73**	**46.84±0.57**	**60.93±6.11**	**1.39±0.16**
	Combo 1	9.74±0.37	51.07±0.76	50.44±3.01	1.06±0.08
	Combo 2	10.03±0.95	48.62±0.37	49.91±4.58	1.08±0.14
37 ^{0}C 1 month	Control	**13.72±0.27**	**47.24±0.74**	**63.19±3.02**	**0.94±0.11**
	Combo 1	11.34±0.28	46.42±0.40	62.92±2.48	1.02±0.16
	Combo 2	9.01±0.65	46.19±0.85	46.35±5.34	0.92±0.12
37 ^{0}C 1 month + 4 ^{0}C 1 week	Control	**15.47±0.69**	**43.39±0.31**	**68.19±5.91**	**1.09±0.09**
	Combo 1	11.32±0.53	46.31±0.39	63.86±5.44	0.94±0.10
	Combo 2	8.90±0.20	46.36±0.68	53.22±3.51	0.80±0.09
37 ^{0}C 1 month + 25 ^{0}C 1 week	Control	**13.89±0.67**	**42.77±0.43**	**65.17±5.38**	**0.90±0.11**
	Combo 1	10.72±0.48	46.91±0.50	62.40±5.66	0.87±0.19
	Combo 2	9.60±0.48	46.42±0.60	49.03±2.45	0.76±0.06

Table 31.Textural parameters of cake samples stored at 50 ^{0}C

Storage conditions	**Cake type**	**Hardness (N)**	**Springiness**	**Toughness (N.s)**	**Gradient**
Initial	Control	**12.41±0.73**	**50.84±0.57**	**60.93±6.11**	**1.39±0.16**
	Combo 1	9.74±0.37	51.07±0.76	50.44±3.01	1.06±0.08
	Combo 2	10.03±0.95	48.62±0.37	49.91±4.58	1.08±0.14
50 ^{0}C 1 month	Control	**14.43±2.20**	**45.32±1.59**	**73.37±7.2**	**1.04±0.25**
	Combo 1	12.22±0.62	45.55±0.66	66.58±4.25	1.27±0.18
	Combo 2	13.19±0.65	45.57±0.71	71.00±7.19	1.24±0.19
50 ^{0}C 1 month + 4 ^{0}C 1 week	Control	**17.89±3.13**	**45.22±1.25**	**90.26±13.41**	**1.63±0.35**
	Combo 1	15.85±1.31	44.23±0.44	82.97±7.12	1.45±0.29
	Combo 2	16.84±1.68	44.26±0.71	86.19±16.04	1.57±0.29
50 ^{0}C 1 month + 25 ^{0}C 1 week	Control	**14.30±0.80**	**47.58±0.62**	**80.49±4.09**	**0.91±0.05**
	Combo 1	12.98±0.38	45.75±0.46	77.29±2.35	0.92±0.07
	Combo 2	13.28±1.03	47.11±0.37	68.54±6.48	1.39±0.22

Table 32. Moisture content and water activity values of cake samples

Storage conditions	Cake type	Moisture content (%)	Water activity
37 ^{0}C 1 month	Control	24.91±0.70	0.832±0.05
	Combo 1	26.25±0.24	0.847±0.07
	Combo 2	25.28±0.04	0.832±0.11
37 ^{0}C 1 month + 4 ^{0}C 1 week	Control	24.12±0.35	0.837±0.30
	Combo 1	25.56±0.71	0.846±0.21
	Combo 2	25.51±0.26	0.848±0.45
37 ^{0}C 1 month + 25 ^{0}C 1 week	Control	24.94±0.24	0.843±0.04
	Combo 1	23.87±0.40	0.845±0.11
	Combo 2	24.69±0.13	0.846±0.31
50 ^{0}C 1 month	Control	25.78±0.67	0.842±0.03
	Combo 1	26.17±0.05	0.849±0.01
	Combo 2	24.82±0.36	0.843±0.07
50 ^{0}C 1 month + 4 ^{0}C 1 week	Control	25.12±0.52	0.842±0.11
	Combo 1	25.22±0.13	0.838±0.15
	Combo 2	24.98±0.05	0.834±0.13
50 ^{0}C 1 month + 25 ^{0}C 1 week	Control	25.30±0.17	0.838±0.09
	Combo 1	25.69±0.04	0.847±0.08
	Combo 2	25.16±0.34	0.843±0.06

Table 33. Multifactor ANOVA results of cake samples stored at 37 ^{0}C and cycled to lower temperatures (4 and 25 ^{0}C)

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
MAIN EFFECTS					
Different formulations	1117.85	2	558.927	94.19	0.0000
Storage temperature	115.754	2	57.8768	9.75	0.0026
RESIDUAL	77.1401	13	5.93385		
TOTAL (CORRECTED)	1310.75	17			

All F-ratios are based on the residual mean square error. P<0.05 significant

Table 34. Multifactor ANOVA results of cake samples stored at 50 ^{0}C and cycled to lower temperatures (4 and 25 ^{0}C)

Source	**Sum of Squares**	**Df**	**Mean Square**	**F-Ratio**	**P-Value**
MAIN EFFECTS					
Different formulations	152.836	2	76.4182	7.90	0.0057
Storage temperature	829.724	2	414.862	42.90	0.0000
RESIDUAL	125.709	13	9.66989		
TOTAL (CORRECTED)	1108.27	17			

All F-ratios are based on the residual mean square error. P<0.05 significant

Table 35. Multiple range test analysis for toughness of cake samples stored at 37 ^{0}C and cycled to lower temperatures (4 and 25 ^{0}C)

Different formulations	**Count**	**LS Mean**	**Homogeneous Groups**
Control	6	69.2633	a
Combo 1	6	63.4767	b
Combo 2	6	50.4217	c
Storage temperatures			
37 ^{0}C (1 month)	6	57.7583	a
4 ^{0}C (1week)	6	63.9267	b
25 ^{0}C (1week)	6	61.4767	b

Different letters indicate statistically significant differences exist at α=0.05 based on multiple range test

Table 36. Multiple range test analysis for toughness of cake samples stored at 50 ^{0}C and cycled to lower temperatures (4 and 25 ^{0}C)

Different formulations	**Count**	**LS Mean**	**Homogeneous Groups**
Control	6	82.1867	a
Combo 1	6	76.4783	b
Combo 2	6	75.6217	b
Storage temperatures			
50^{0}C (1 month)	6	70.9917	a
4^{0}C (1week)	6	87.2417	b
25^{0}C (1week)	6	76.0533	c

Different letters indicate statistically significant differences exist at α=0.05 based on multiple range test

5.5.2 Evaluation of thermal parameters

Starch retrogradation can be defined as the reassociation of molecules to form an ordered structure after gelatinization. The kinetics of starch crystallization depends on several factors such as storage temperature and starch concentration. Storage of cake samples at 50 ^{0}C accelerated the starch retrogradation compared to storage conditions at 37 ^{0}C (Figures 28 and 30). These samples had more crystalline structures. Decreasing the storage temperatures to 25 and 4 ^{0}C for 1 week caused changes in crystallization rate of cake samples (Figures 29-32). Regardless of the storage temperatures control cake had the highest starch retrogradation. On the other hand refrigeration of cake samples accelerated the starch retrogradation rate slightly. Combination formulation 2 had the lowest amount of crystalline structures in all storage conditions (Figures 28-32). Thermal properties of the cake samples were also evaluated. One of the most important parameters of interest was the enthalpy value. Enthalpy value of a system is a thermodynamic property in a system which indicates the amount of energy available in a system. Enthalpy values of storage retrogradation peak were highest for control cake in each storage conditions. Temperature drop from high to lower temperatures resulted in higher enthalpy values which was an indicator of increased starch retrogradation (Tables 37 and 38).

Wide angle x-ray diffraction profiles were plotted intensity versus 2ϴ of cake samples within the range of $10 < 2\theta < 46$. The presence of crystallinity was confirmed by the presence of peaks in the diffraction patterns. We compared the crystallinity of native starches and confirmed that the origin of crystal structures in the XRD graphs were associated with those of native starches. Native cereal starch shows *A* type crystallinity with the principal peaks appearing 15°, 17° and 23.4° of 2θ (Becker *et al*., 2001). The cake samples showed two principal peaks around 13° and 21^{o} of 2θ which is an indicator of the V_h pattern. Mechanical hardness and toughness values were found to increase with increased relative crystallinity. Percentage of relative crystallinity values of cake samples increased with the increase in storage temperature. Cake formulations which were developed by Rutgers University Food Science department showed less crystalline starch structures compared to the control cake under the same storage conditions (Table 39). The findings from both the differential scanning calorimeter and X-ray diffractometer were in good agreement with each other.

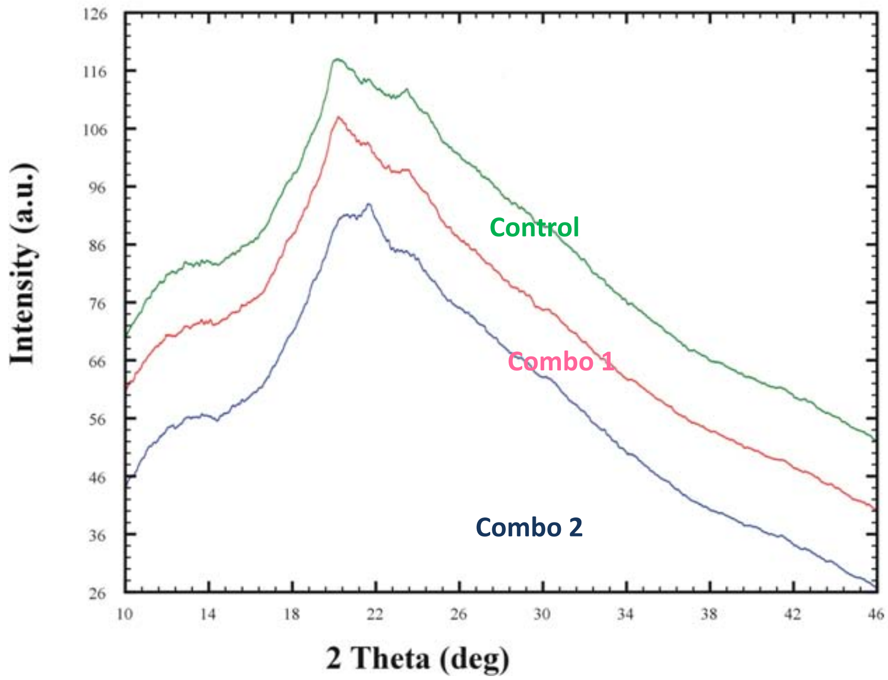


Figure 28. XRD graph of cake samples stored at 37 ^{0}C for 1 month

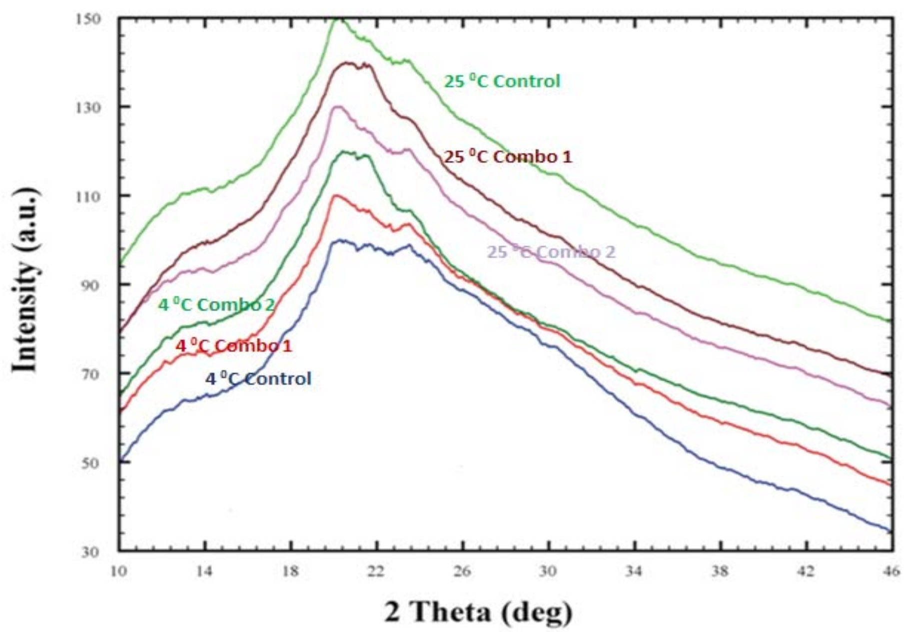


Figure 29. XRD graph of cake samples stored at 37 ^{0}C for 1 month and then transferred to 25 and 4 ^{0}C for 1 week.

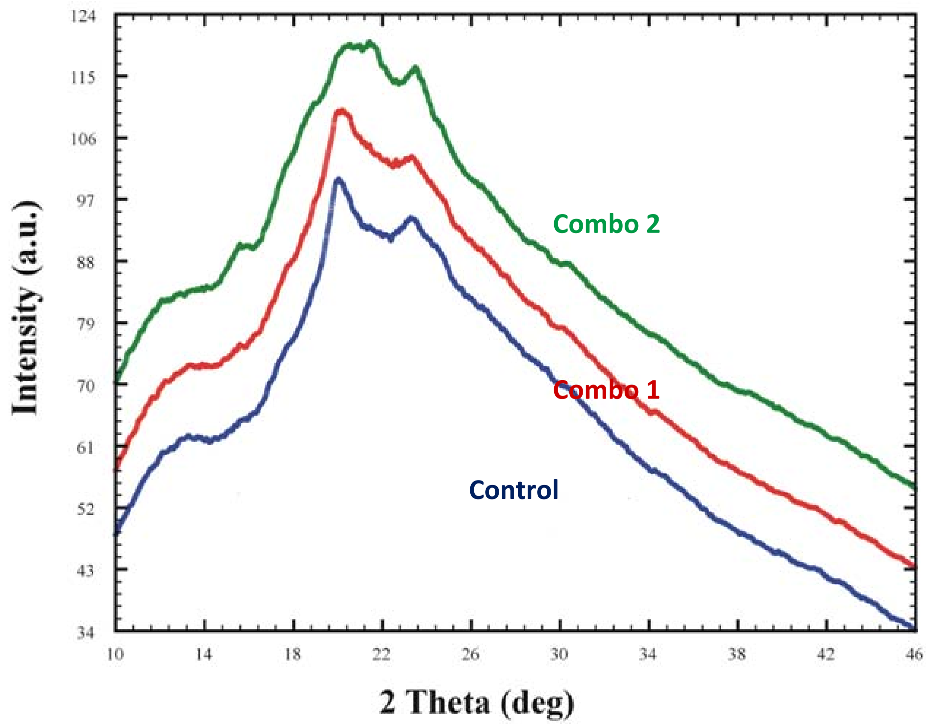


Figure 30. XRD graph of cake samples stored at 50 ^{0}C for 1 month

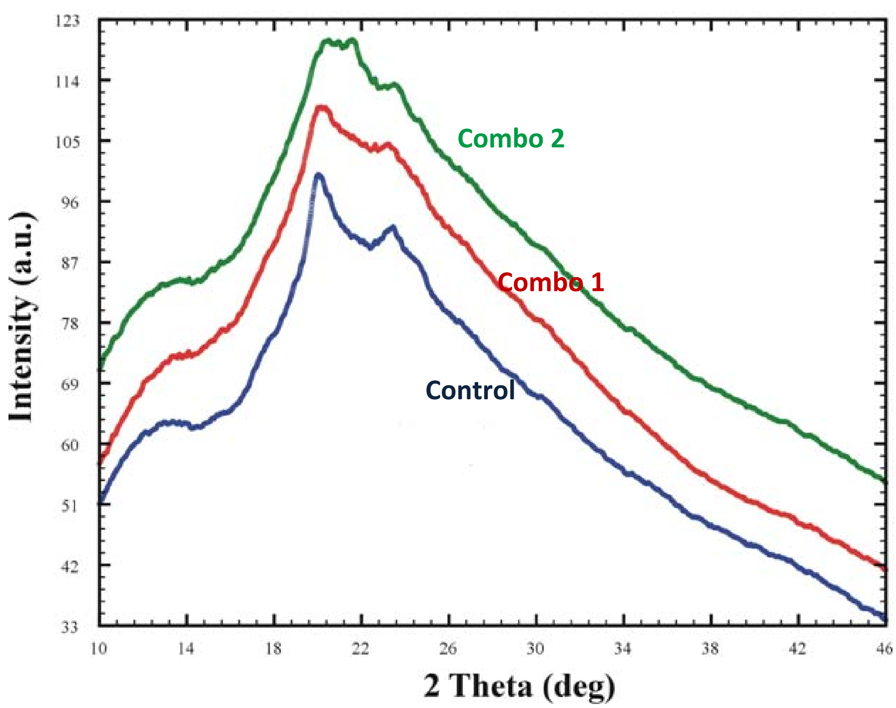


Figure 31. XRD graph of cake samples stored at 50 ^{0}C for 1 month and then transferred to 4 ^{0}C for 1 week.

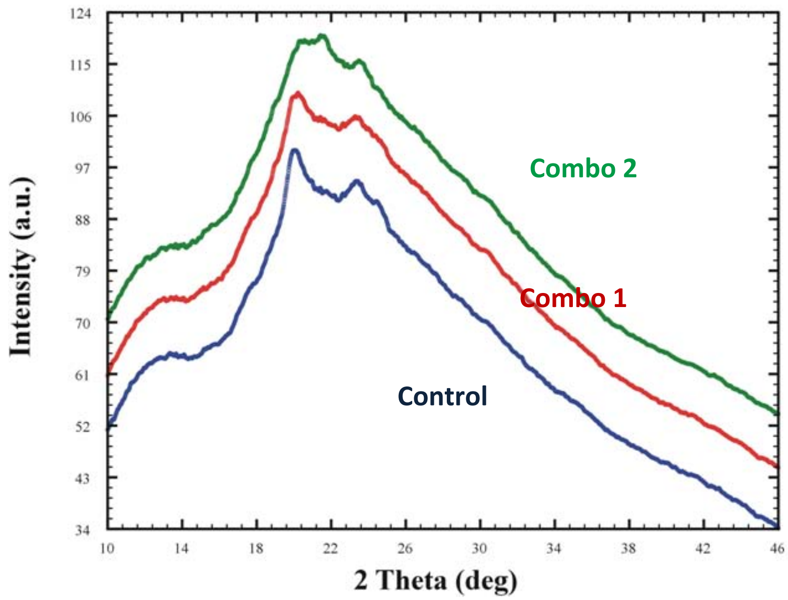


Figure 32. XRD graph of cake samples stored at 50 ^{0}C for 1 month and then transferred to 25 ^{0}C for 1 week.

Table 37. Thermal properties of cake samples stored at 37 ^{0}C

37 ^{0}C 1month	**T_{onset} (^{0}C)**	**T_{mid} (^{0}C)**	**T_{end} (^{0}C)**	**Enthalpy (J/g)**
Control	52.43	58.46	61.78	0.41
Combo 1	53.26	58.95	62.21	0.31
Combo 2	52.90	58.45	61.60	0.30
37 ^{0}C 1month 4 ^{0}C 1week				
Control	37.85	46.97	61.25	1.15
Combo 1	39.81	48.32	61.46	0.90
Combo 2	39.61	47.65	61.73	0.84
37 ^{0}C 1month 25 ^{0}C 1week				
Control	37.30	57.89	61.53	1.41
Combo 1	39.10	47.13	59.81	0.87
Combo 2	39.43	46.82	60.63	0.82

Table 38. Thermal properties of cake samples stored at 50 ^{0}C

50 ^{0}C 1month	**T $_{onset}$ (^{0}C)**	**T $_{mid}$ (^{0}C)**	**T$_{end}$ (^{0}C)**	**Enthalpy (J/g)**
Control	48.78	53.41	59.01	0.49
Combo 1	50.93	54.53	58.40	0.35
Combo 2	34.62	45.05	48.96	0.39
50 ^{0}C 1month 4 ^{0}C 1week				
Control	49.65	52.69	60.09	1.35
Combo 1	48.06	53.55	61.16	1.05
Combo 2	46.77	48.58	52.33	0.93
50 ^{0}C 1month 25 ^{0}C 1week				
Control	50.10	53.56	58.15	1.51
Combo 1	50.03	54.69	60.85	0.95
Combo 2	37.68	44.43	49.38	0.89

Table 39. % Relative crystallinity (Σ area under peaks/area of amorphous region)

	37^0C 1month	**37^0C 1month + 25^0C 1 week**	**37^0C1month + 4^0C 1 week**
Control	2.32	5.70	8.09
Combo 1	0.51	1.70	3.42
Combo 2	0.65	2.02	4.00
	50 ^{0}C 1month	**50^0C 1month + 25^0C 1 week**	**50^0C1month + 4^0C 1 week**
Control	4.23	7.23	10.73
Combo 1	2.20	3.37	6.50
Combo 2	1.10	2.78	6. 73

5.5.3 Evaluation of image analysis data

Most of the fermented bakery products consist of cellular structures. Control of cake cellular structure would be useful to understand the effect of ingredients, processing and storage to the product texture. The cellular structures of control, combination 1 and combination 2 cake samples were evaluated by the use of image analysis technique. Non destructive X-ray microtomography technique (XMT) was used to analyze cellular structure of the samples. Cake samples were taken from the center of each tray and put into transparent zip lock bags in order to avoid from moisture loss.

Analysis of XMT images of cake samples (Figure 33) showed that cellularity of control, combo 1 and combo 2 samples varied from 276 to 544 pores/cm^2 with a t/R ratio of 0.48 to 0.89. Generally, all the cake samples consisted of several small pores which have pore area between 0.12-0.18 (Table 40 and Table 41). The toughness of the cakes depended on cell density, size and

shape of the pores. High t/R ratio indicated thick cell walls where the resistance to deformation was very high. Both toughness and t/R ratio for cake samples stored at 50 ^{0}C were higher than the cake samples stored at 37 ^{0}C (Table 40-42).

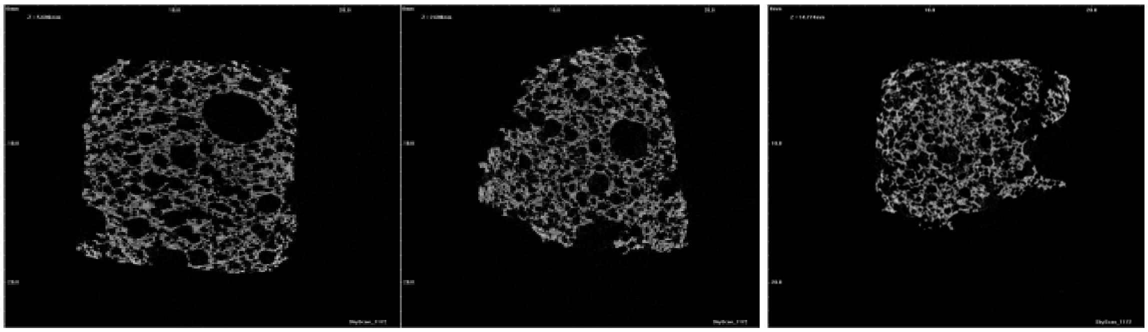


Figure 33. XMT cross section images of control, combo1 and combo 2 cake samples

Table 40. Parameters of image analysis for cake samples kept at 37 ^{0}C

Storage conditions	**Cake type**	**Ave cell area (mm^2)**	**Ave cell radius (mm) R**	**Cell density # cell/cm^2**	**Ave cell thickness (mm) t**	**t/R**	**PDI (poly dispersity index)**
37 ^{0}C 1 month	Control	0.14	0.22	367	0.1452	0.66	17.10
	Combo 1	0.14	0.23	366	0.1564	0.68	12.54
	Combo 2	0.15	0.25	300	0.1200	0.48	15.93
37 ^{0}C 1 month + 4 ^{0}C 1 week	Control	0.16	0.23	343	0.1633	0.71	16.23
	Combo 1	0.15	0.22	346	0.1496	0.68	14.19
	Combo 2	0.17	0.25	286	0.1400	0.56	14.00
37 ^{0}C 1 month + 25 ^{0}C 1 week	Control	0.13	0.21	348	0.1449	0.69	10.72
	Combo 1	0.17	0.21	323	0.1407	0.67	15.39
	Combo 2	0.12	0.23	332	0.1265	0.55	20.32

Table 41. Parameters of image analysis for cake samples kept at 50 ^{0}C

Storage conditions	**Cake type**	**Ave cell area (mm^2)**	**Ave cell radius (mm) R**	**Cell density # cell/cm^2**	**Ave cell thickness (mm) t**	**t/R**	**PDI (poly dispersity index)**
50 ^{0}C 1 month	Control	0.13	0.21	544	0.1449	0.69	14.32
	Combo 1	0.18	0.24	276	0.1392	0.58	23.21
	Combo 2	0.16	0.22	357	0.1496	0.68	20.61
50 ^{0}C 1 month + 4 ^{0}C 1 week	Control	0.18	0.19	305	0.1691	0.89	13.32
	Combo 1	0.14	0.20	363	0.1520	0.76	10.58
	Combo 2	0.14	0.20	329	0.1600	0.80	13.59
50 ^{0}C 1 month + 25 ^{0}C 1 week	Control	0.15	0.21	321	0.1575	0.75	15.26
	Combo 1	0.14	0.22	346	0.1606	0.73	12.39
	Combo 2	0.13	0.19	292	0.1349	0.71	11.23

We investigated the effect of t/R ratio on the toughness of cake samples. As storage temperature increased t/R ratio of samples increased indicating the increase in pore thickness (Figures 34 and 35). Cakes are in the group of cellular solid foods. As the thickness of cells/pores increased they were expected to show more resistance to the applied forces. As a result of this we obtained higher toughness values for samples with high t/R ratio (Table 42). The change in cell wall thickness might be related with the change in water mobility and relocalization of water molecules during starch retrogradation.

Table 42. Toughness values of cake samples kept at 37 ^{0}C

Storage conditions	Cake type	Toughness (N.s)	Storage conditions	Toughness (N.s)
37 ^{0}C 1 month	Control	**63.19±3.02**	50 ^{0}C 1 month	**73.37±7.2**
	Combo 1	62.92±2.48		66.58±4.25
	Combo 2	46.35±5.34		71.00±7.19
37 ^{0}C 1 month + 4 ^{0}C 1 week	Control	**68.19±5.91**	50 ^{0}C 1 month + 4 ^{0}C 1 week	**90.26±13.41**
	Combo 1	63.86±5.44		82.97±7.12
	Combo 2	53.22±3.51		86.19±16.04
37 ^{0}C 1 month + 25 ^{0}C 1 week	Control	**65.17±5.38**	50 ^{0}C 1 month + 25 ^{0}C 1 week	**80.49±4.09**
	Combo 1	62.40±5.66		77.29±2.35
	Combo 2	49.03±2.45		68.54±6.48

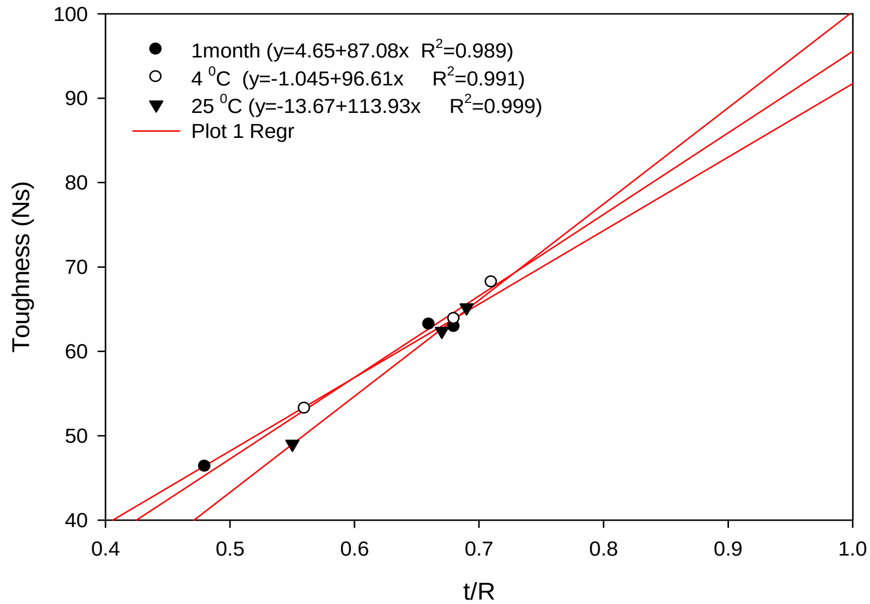


Figure 34. Effect of t/R ratio on cake toughness during storage conditions at 37 ^{0}C

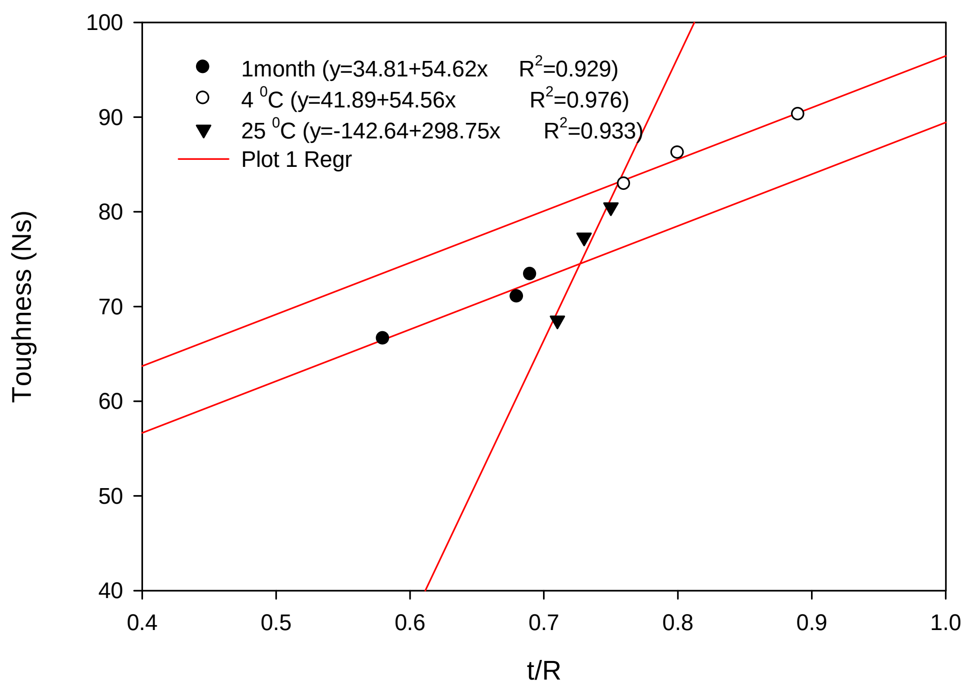


Figure 35. Effect of t/R ratio on cake toughness during storage conditions at 50 ^{0}C

5.6 Long term shelf life testing of commercial Devil's Fudge cakes

During storage of cakes some quality related characteristics such as moisture loss, starch retrogradation, loss of flavor/aroma and increased firmness could occur. Freshly baked cake is soft and elastic however staling can lead to a cake which is crumbly in texture. Staling is a complex phenomenon which is associated with low consumer acceptance. Despite the high number of scientific research on the mechanism of staling, staling still it is not well-defined. In the literature most of the attention in terms of staling has been given to bread staling. Bread as a food system is less complex then cake due to its relatively simple formulation. In order to better understand the textural and quality problems associated with staling we did long term storage testing on commercial Devil's Fudge cakes. The cake samples were stored at 4, 25, 37 and 50 ^{0}C inside polytrays. The storage periods associated with cakes were 4 and 5 months for 4 and 25 ^{0}C, respectively. They were stored for 7 months for 37 and 50 ^{0}C. After 7 months of storage of cakes at 37 ^{o}C and 50 ^{o}C, it was found that the toughness values were 92.15 and 97.01 Ns, respectively (Table 43). The samples that were stored at 50 ^{o}C were darker in color and there were some visible cracks on the surface. The samples that were stored at 50 ^{o}C had off-odor as well.

Figure 36. Pictures of commercial cake samples stored at 37 ^{o}C (left) and 50 ^{o}C (right) for 7 months

Table 43. Textural parameters of commercial Devil's Fudge after long term storage at 4, 25, 37 and 50 ^{0}C

Storage temperature (^{o}C)	**Month**	**$F_{rupture}$ (N)**	**Toughness (Ns)**	**$D_{rupture}$ (mm)**	**Springness**	**Gradient**
4	1	16.46±0.35	100.28±8.88	10.08±0.22	45.22±1.28	2.15±0.75
	2	17.10±1.27	92.13±17.58	9.57±0.29	47.00±1.27	2.04±0.58
	3	19.63±0.76	103.57±9.55	9.74±0.36	49.18±0.54	2.82±0.46
	4	22.81±2.06	113.49±12.22	9.46±0.29	49.63±0.55	3.51±0.69
	5	No samples at this temperature				
	7					
25	1	16.60±1.28	82.55±8.62	9.56±0.41	47.37±0.65	2.04±0.38
	2	16.69±2.03	85.20±10.16	9.74±0.53	47.45±1.11	2.11±0.50
	3	17.74±2.03	106.41±16.42	10.02±0.37	47.74±0.90	2.17±0.29
	4	19.51±1.46	103.00±8.20	9.44±0.28	50.23±0.38	2.63±0.50
	5	17.21±1.23	90.24±12.20	9.35±0.26	49.63±1.29	1.08±0.33
	7	No samples at this temperature				
37	1	11.89±0.62	74.10±6.79	10.75±0.66	47.51±1.20	1.58±0.33
	2	12.48±0.92	66.09±5.61	9.98±0.29	48.86±0.53	1.58±0.25
	3	14.27±1.67	67.15±6.73	9.44±0.32	48.43±0.59	2.17±0.41
	4	16.64±0.76	86.93±4.35	9.22±0.38	50.24±0.65	2.00±0.46
	5	13.86±1.48	72.98±6.94	9.37±0.28	47.02±0.79	1.04±047
	7	17.56±1.67	92.15±8.91	9.23±0.31	47.41±0.83	1.39±0.32
50	1	13.42±0.81	64.61±8.61	10.00±0.23	49.52±0.61	1.68±0.32
	2	14.41±0.82	85.87±12.52	10.77±0.64	50.92±0.52	1.78±0.18
	3	15.31±1.12	79.05±8.19	9.80±0.45	47.15±0.67	2.10±0.26
	4	21.34±2.43	114.43±12.39	9.44±0.34	49.44±1.18	2.29±0.29
	5	47.41±0.73	79.22±7.85	16.77±1.09	9.25±0.29	1.62±0.21
	7	18.52±2.92	97.01±18.47	9.73±0.44	46.48±0.68	1.55±0.41

We also compared the commercial cakes with the new formulated cake samples after storing them for 1, 4 and 6 months at 37^{0}C and 1 and 2 months at 50 ^{0}C. We found that the new cake samples which were stored at 37 ^{0}C had approximately 25 % less hardness and toughness values than the commercial cake (Table 44). We also found improvement of textural properties in both combination formulations after a storage period of two months at 50 ^{0}C. The toughness value of cakes, which was a good indicator of starch retrogradation, was found to be lower for all three formulations including the control than the commercial cake (Table 45). The thermal measurements were also supporting the results from the texture analyzer. The enthalpy value of each cake was evaluated from the area under the retrogradation peak. The enthalpy values were found to increase with storage time as a result of increased starch crystallinity (Figure 37 and Table 46).

Table 44. Texture parameters of cake samples stored at 37 ^{0}C

Cake samples	**Hardness (N)**	**Springiness**	**Toughness (Ns)**	**Gradient**
Commercial_1m	11.89±0.62	47.51±1.20	74.10±6.79	1.58±0.33
Commercial_4m	16.64±0.76	50.24±0.65	86.53±4.35	2.00±0.46
Commercial_19m	20.94±1.64	50.21±0.28	117.94±6.19	1.77±0.32
Control_1m	11.40±0.60	46.41±0.92	62.39±5.71	1.49±0.26
Control_4m	11.28±0.57	44.62±0.61	67.63±5.89	0.92±0.12
Control_6m	11.51±0.47	44.84±0.44	70.25±6.74	1.50±0.19
Combo1_1m	8.55±0.38	45.34±0.98	45.72±3.84	0.98±0.14
Combo1_4m	10.23±1.06	43.72±0.44	56.23±5.99	0.88±0.14
Combo1_6m	10.68±0.84	42.61±0.73	57.19±5.43	1.01±0.23
Combo2_1m	7.11±0.98	45.05±0.90	34.23±8.14	0.84±0.19
Combo2_4m	10.24±0.99	44.33±0.50	46.77±3.01	1.19±0.29
Combo2_6m	10.82±0.27	44.01±0.44	47.28±1.89	1.12±0.05

Table 45. Texture parameters of cake samples stored at 50 ^{0}C

Cake samples	Hardness (N)	Springiness	Toughness (Ns)	Gradient
Commercial_1m	13.42±0.81	49.52±0.61	64.61±8.61	1.68±0.32
Commercial_2m	14.41±0.82	50.92±0.80	85.87±12.52	1.78±0.18
Control_1m	10.66±0.81	46.01±1.22	56.34±7.93	1.54±0.23
Control_2m	12.04±0.41	43.48±0.59	71.41±2.49	1.69±0.13
Combo1_1m	8.86±1.08	45.53±0.75	44.51±7.58	1.18±0.14
Combo1_2m	9.34±0.80	43.72±0.55	51.68±5.46	1.19±0.12
Combo2_1m	10.85±1.58	44.81±1.41	50.69±7.38	1.34±0.20
Combo2_2m	14.51±1.49	43.53±0.56	60.51±9.23	1.98±0.21

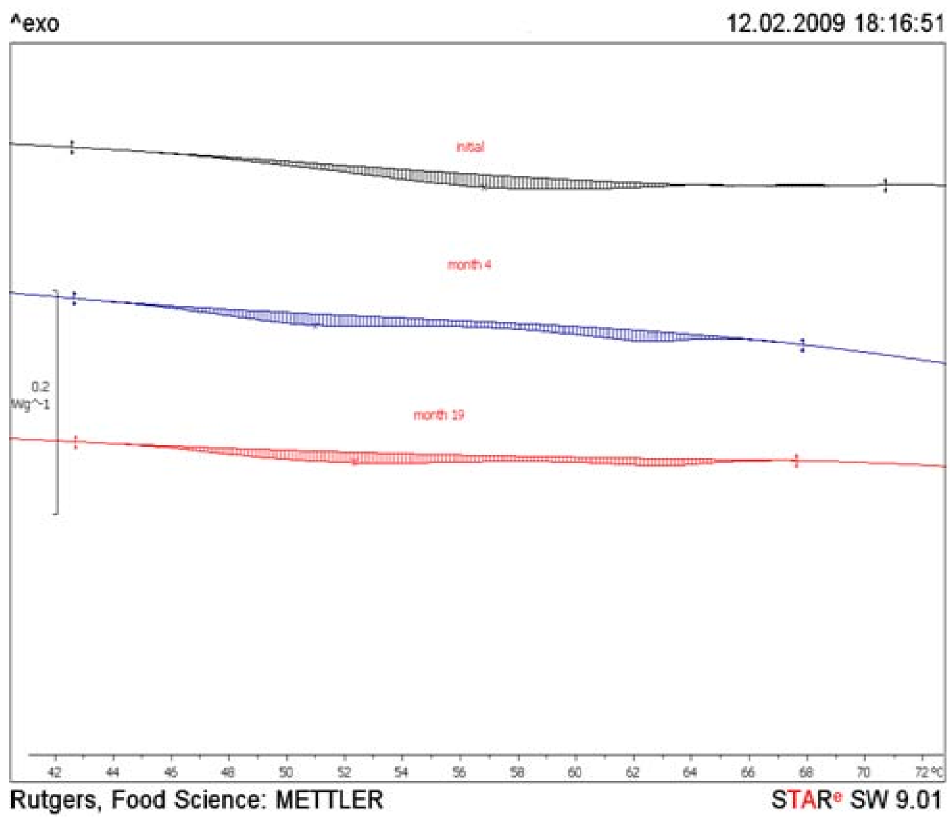


Figure 37. Differential Scanning thermograms of commercial cakes

Table 46. Enthalpy values of commercial cake samples stored at 37 ^{0}C temperature

Commercial cake storage time	**T_{onset} (^{0}C)**	**T_{peak} (^{0}C)**	**T_{end} (^{0}C)**	**Enthalpy (J/g)**
Initial	47.37	56.58	63.82	0.64
Month 4	42.97	50.86	65.12	0.83
Month 19	44.42	52.24	63.49	0.94

5.6.1 Instrumental and sensorial comparison of textural parameters

Sensory analysis was carried out to find the relationship between sensory and instrumental measurements of cake samples. Cake samples were taken after 1 month of storage at 37 and 50 ^{0}C and accompanying 1 week storage at 4 and 25 ^{0}C. The sensory test panel consisted of 10 panellists (5 female and 5 male, 24-50 years old) selected from previously trained graduate students and academic staff. Panellists received training to define textural terms for the cake samples two weeks before test. The following textural parameters were evaluated: toughness, the resistance of cake to compression by the teeth, was measured by compressing the cake against the palate with the tongue. Springiness was measured as the degree to which the product returns to its original shape after partial compression (without failure) between the tongue and palate or teeth. Dryness to the mouth was evaluated by the tendency of the cake to absorb saliva during chewing. Each of these five parameters was evaluated on a scale ranging from 0 to 9 (Szczesniak et al., 1963). The correlation between instrumental and sensory textural parameters were evaluated by the help of Pearson's correlation matrix. Table 47 shows the results of Pearson's correlation matrix for cake samples which were stored at 50 ^{0}C for 1 month. We hypothesized that sensory feeling of dryness inside the mouth would be positively correlated with toughness. We found that instrumental toughness was correlated with sensory toughness. Sensory dryness and instrumental toughness were significantly positively correlated. Instrumental springiness and toughness was found to be negatively correlated for cake samples stored at 37 ^{0}C 1 month

(Table 48). Sensory toughness and instrumental toughness was highly correlated. Sensory toughness and instrumental springiness was highly negatively correlated.

Table 47. Pearson's correlation matrix for cake samples stored at 50 ^{0}C 1 month

	I -Toughness	**I-Springiness**	**S-Springiness**	**S-Toughness**	**S-Dryness**
I-Toughness	1				
I-Springiness	-0.101	1			
S-Springiness	-0.324	0.335	1		
S-Toughness	0.609**	-0.119	-0.045	1	
S-Dryness	0.567*	-0.048	-0.042	0.507	1

(I-instrumental S-sensory values)

Table 48. Pearson's correlation matrix for cake samples stored at 37 ^{0}C 1 month

	I-Toughness	**I-Springiness**	**S-Springiness**	**S-Toughness**	**S-Dryness**
I-Toughness	1				
I-Springiness	-0.513*	1			
S-Springiness	-0.302	0.331	1		
S-Toughness	0.562**	-0.616**	-0.045	1	
S-Dryness	0.117	0.195	-0.076	-0.265	1

5.7 Transfer of knowledge for pancake and waffle production

Our second group of bakery products was pancakes and waffles. The object of the second part of this project was to provide pancakes and waffles complete in flavor, texture and appearance as freshly prepared pancakes and waffles with higher degree of consumer perception. There was hardly any previous search in the literature on pancake and waffles. According to a request from NATICK in our studies we focused more on waffles than the pancakes. Both pancakes and waffles are much more different than the previous cake samples in terms of formulation. In formulating pancakes and waffles the amount of sugar and fat which are one of the key ingredients in starch retrogradation is less as compared to high ratio cake formulations.

5.7.1 Pancake production

For pancakes springiness is the most important textural criteria in terms of consumer perception (Seguchi et al., 1998) besides toughness which is related with staling. It was indicated that the desired springiness can be achieved either by using chlorinated flour or heat treatment to cake flour (120 ^{o}C, 2 hrs). Aged wheat flour has different hydrophobic properties for the starch and protein. Starch granules become hydrophobic in nature due to aging. Another study done by the same authors claimed that springiness of a pancake could be improved by using flour previously heated at 120 ^{o}C for 5 hr. Heat treatment at 100 ^{o}C for 10 hr resulted in an increased springiness and reduced gumminess similar to chlorinated or long term stored flour. Heat treatment may split some of the linkages of starch amylose and/or amylopectin chains, resulting in lowering the optimum viscosity of wheat flour. Surface protein wheat starch granules have been reported to develop a hydrophobic (lipophilic) character by chlorination or heat treatment of wheat flour. Hydrophobic wheat starch granules may stabilize air bubbles in pancake batter. Production of pancakes is summarized in the flow chart below (Figure 38).

Flour

+

Powdered sugar

+

Sodium bicarbonate

Mix with a flat beater (Kitchen Aid) at 112 rpm for 30 sec

Transfer the batter into an iron pan (12 cm dia, 2.5 cm depth)

Bake in an oven at 170-180 ^{o}C first for 10 min and then another 3 min for the other side.

Figure 38. Flow diagram of pancake production

5.7.2 Waffle production

Both pancakes and waffles are classified as pourable batter-style quick breads. They are quite similar in ingredients and usage proportions. The batters are simply based on flour, leavening,

sweetening and liquid ingredients such as milk, oil and eggs. Pancakes are made on a griddle whereas waffles are made on waffle iron. Waffles lose their crispness very quickly and pancakes toughen when they are held. However there are some differences in both batter formulations. Waffles are richer in fat content and thicker. Their structure is more open with bigger cell sizes. During batter preparation mixing is the most critical step since over mixing will cause excessive gluten development. This will result in a batter which has high viscosity, difficult to pour and non-expandable. Batter viscosity is important in the production of pancakes and waffles to ensure that the finished product has a consistent shape. Figure 39 summarizes the flow diagram and critical points of waffle production.

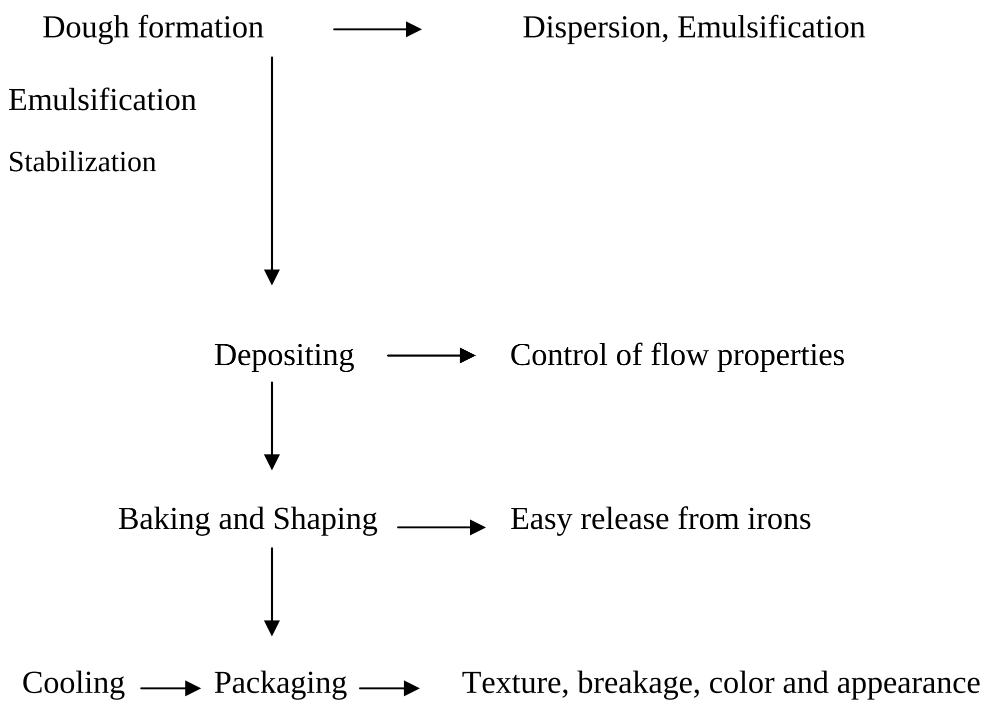


Figure 39. Flow diagram and critical points in waffle production

For the waffle production our starting point was the NATICK formulation which resulted in a very thick batter difficult to deposit to the baking iron. As a result of baking difficulties we developed a new batter which had a lower viscosity (Table 49). The NATICK waffle had a water activity of 0.85 after baking. Because of high viscosity level it was difficult for the water to evaporate causing an increase in water activity. The control waffles which were produced by Rutgers Food Science had a water activity of 0.743 after four minutes of baking at high temperature. The water activity level dropped to 0.726 when they were baked at medium

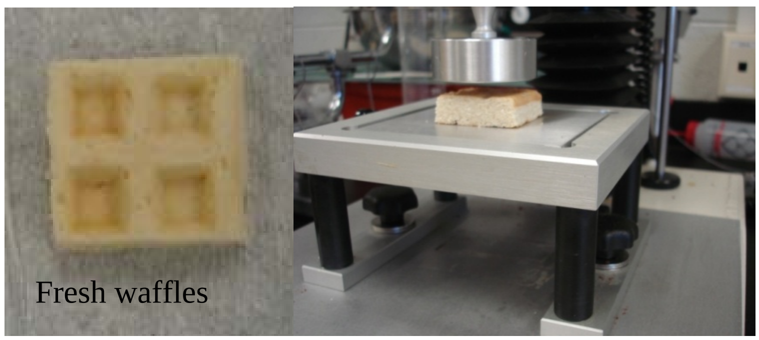
temperature for the same baking time. The initial hardness value for medium temperature cooked samples was 23.97 N which increased to 36.15 N after one day and finally 45.18 N after three days of storage inside plastic bags at room temperature. The staling rate for the waffles was higher than the cakes.

Table 49. Percentages of ingredients used in the NATICK and Rutgers formulations

Ingredient (%)	**Control**	**Formula A**	**Formula B**	**Formula C**
Water	37.27	39.27	39.90	39.25
Flour	31.86	28.50	28.96	28.50
Sugar	15.03	12.47	12.68	12.48
Dried egg powder (whole)	2.40	2.15	2.18	2.15
Shortening	12.04	10.75	10.93	10.75
Glycerol	-	4.30	2.73	4.30
Salt	-	0.75	0.76	0.75
Baking powder	1.20	1.07	1.09	1.08
Instant starch	-	0.54	0.55	0.54
Xanthan gum	-	0.02	0.01	0.02
Antimicrobial agent (Potassium sorbate)	0.20	0.18	0.21	0.18
Enzyme (α-amylase)	-	-	-	0.0002

5.7.2.1 Textural characterization of waffle samples

Waffles samples were cut into identical square pieces (3cm). Deformation tests were done by the use of a texture analyzer. Details of the methodology were previously described in materials and methods part of this report. Pictures of fresh and aged waffles (inside MRE pouches 2 weeks at room temperature) are given in Figure 40 together with the picture of the compression test.



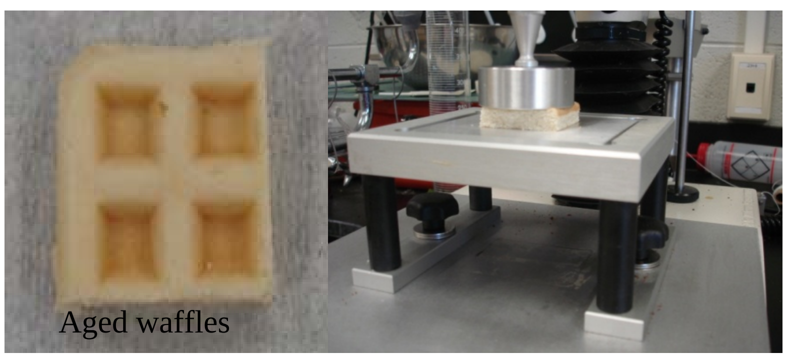


Figure 40. Rutgers University control waffle formulations

By the increase of storage time it was found that both textural and physical properties changed regardless of the formulation. These changes in both textural and physical properties were more severe and occurred faster than the cake samples. Aged waffle samples became pale in color and some of the samples shrank. While performing textural measurements on aged waffle samples

two different protocols were followed. The first measurement technique consisted of performing textural measurements directly on the waffle samples and the second one each waffle sample was pre-heated prior to measurements. By heating we found that both hardness and toughness values which were associated with staling decreased as compared non-heat treated samples (Figures 42-43). However, these values were still higher than the initial textural parameters. This showed us that by the application pre-heating before consumption the adverse effects of staling on textural properties can be reversed. By the application of pre-heating it was also found that springiness values slightly increased (Figure 44). Table 50 summarizes the numerical values of textural parameters for each formulation. There was a gradual increase in toughness and hardness values and a decrease in springiness values by storage time. The changes in textural parameters were faster for the initial 1 week storage period at room temperature. Among all the formulations, formula A gave the most promising results in terms of textural and physical measurements.

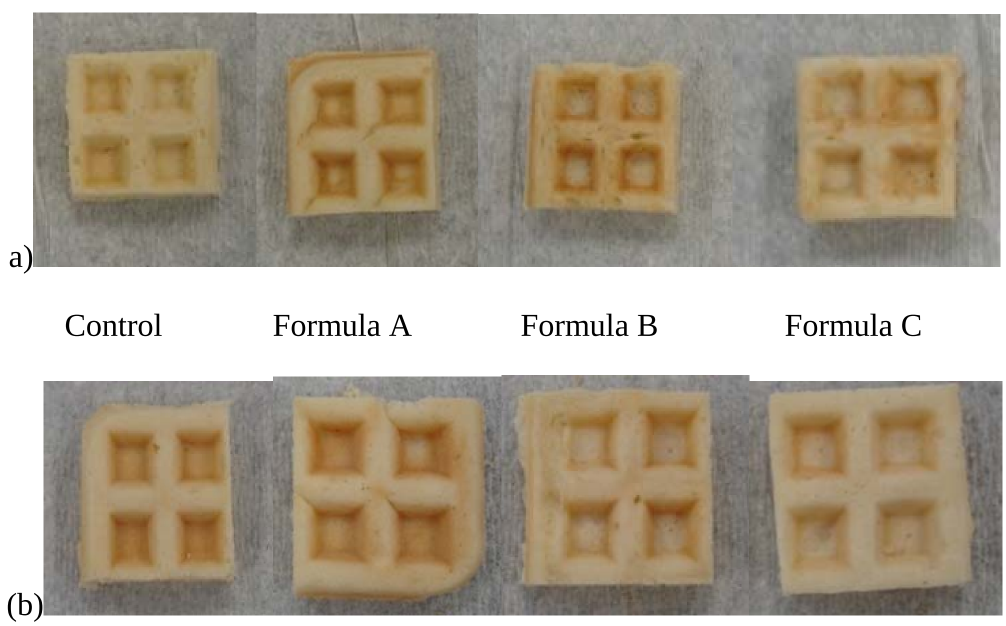


Figure 41. Picture of waffle samples (a) freshly baked (b) stored at room temperature for 2 weeks

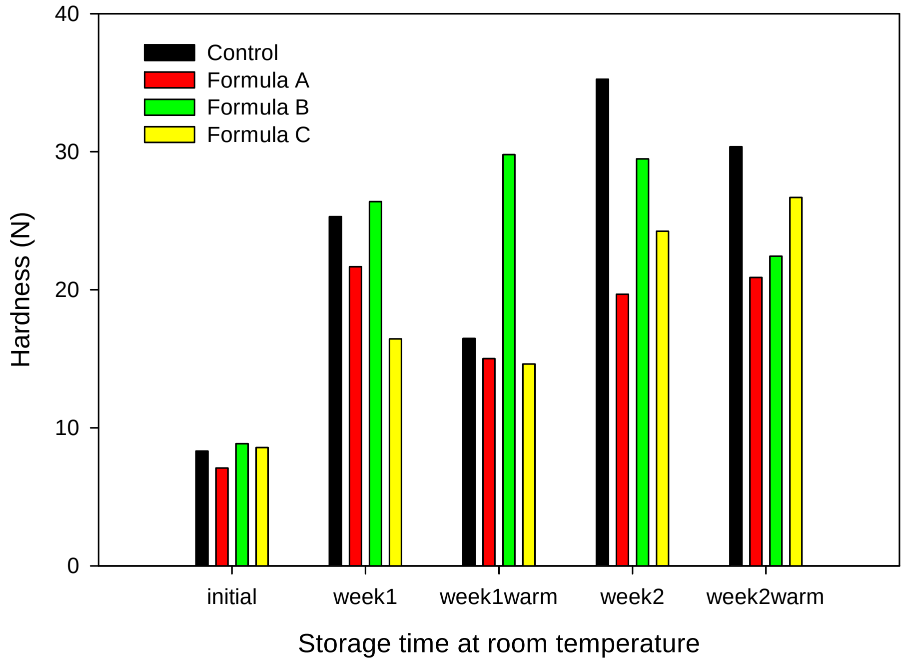


Figure 42. Hardness values of waffle samples

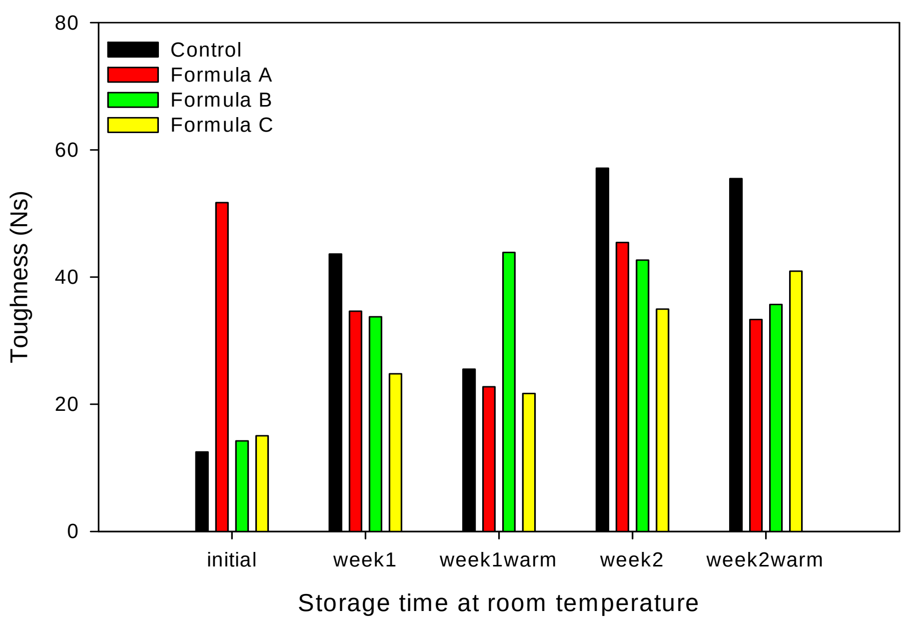


Figure 43. Toughness values of waffle samples

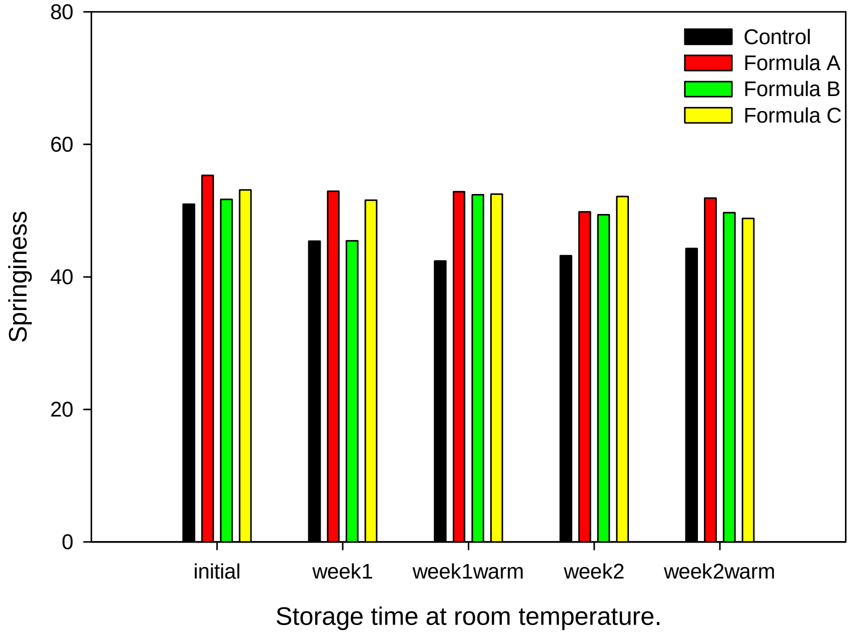


Figure 44. Springiness values of waffle samples

Table 50. Textural parameters of waffle samples

	Hardness (N)	**Springiness**	**Toughness (Ns)**
Initial values			
Control	8.31±0.52	50.97±2.78	12.49±0.85
Formula A	7.08±1.84	49.82±1.68	11.19±3.18
Formula B	8.85±1.25	45.43±2.14	14.22±2.42
Formula C	8.43±1.45	47.02±1.89	15.22±1.59
1 week storage at 25 ^{0}C			
Control	25.30±3.20	45.38±1.14	43.59±4.02
Formula A	19.68±2.09	55.35±1.07	30.87±3.56
Formula B	26.38±3.41	51.70±1.56	33.15±1.16
Formula C	16.44±3.62	51.58±0.51	24.78±2.67
2 week storage at 25 ^{0}C			
Control	35.23±2.84	43.19±1.72	52.12±4.54
Formula A	21.66±4.52	52.93±1.24	34.62±3.28
Formula B	29.48±2.21	49.39±0.74	42.66±3.43
Formula C	24.23±3.50	52.13±1.15	34.96±2.10

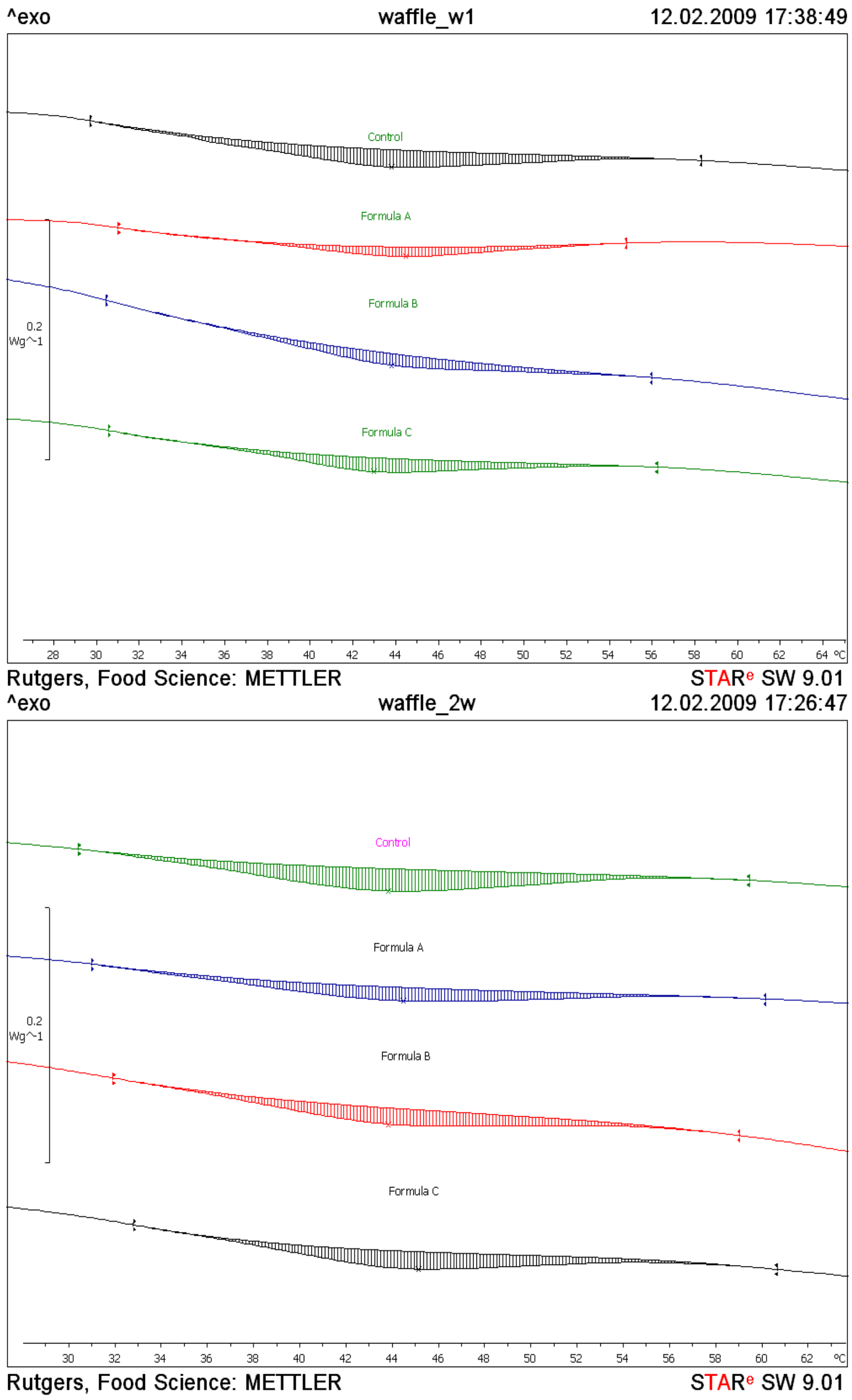


Figure 45. DSC thermograms of waffle samples

Table 51. Thermal characterization of waffle samples

Waffle types	**T_{onset} (^{0}C)**	**T_{peak} (^{0}C)**	**T_{end} (^{0}C)**	**Enthalpy (J/g)**
week 1 at 25 ^{0}C				
Control	33.98	43.69	54.87	1.63
Formula A	30.90	44.38	52.55	0.39
Formula B	31.65	43.61	55.86	0.57
Formula C	36.98	42.86	52.65	0.67
week 2 at 25 ^{0}C				
Control	32.88	43.66	54.94	1.34
Formula A	33.66	44.28	55.21	0.80
Formula B	34.50	43.60	54.14	0.87
Formula C	35.71	44.98	54.97	0.91

Similar to all starch containing bakery products DSC thermograms of aged waffle samples showed a clear starch retrogradation peak around 50 ^{0}C. The peak area increased with storage time which showed the presence of more crystalline structures. The enthalpy value of the starch retrogradation peak was the lowest for formula A which was in good agreement with the textural measurements (Table 51).

6 CONCLUSIONS

The outcomes of this project can be summarized as follows;

1. In our study we used various ingredient strategies (emulsifiers, surfactants, enzymes, high sugar and fat, gum technology) to improve textural stability of devil's fudge cakes.

2. Storage temperature together with ingredients was found to be effective on controlling staling rate.

3. At different storage conditions surfactant (PS60), enzyme (alpha amylase) and emulsifiers containing formulations gave the lowest toughness scores indicating less starch staling. Thus we created two different combination formulations.

4. Staling rate was found to be lowest for low storage temperatures and it increased with temperature cycling from high to lower temperatures.

5. From Pearson's correlation matrix we found that sensorial toughness and instrumental toughness was significantly correlated.

6. It was found that for all the cake formulations there was a decrease in both hardness and toughness values whereas springiness values did not change much. The basic differences within formulations were created by incorporation of gums, enzymes, soluble fibers, emulsifiers, and modified flours

7. t/R ratio which we obtained from image analysis of XRT pictures was positively correlated with toughness values.

8. The enthalpy values for melting of starch crystals were found to increase with storage time.

9. After long term storage we found that all RU formulations had lower staling rates than the current product.

10. We successfully implemented a production and ingredient protocol for waffles with our knowledge from the cake project.

11. The starch retrogradation rate in waffles are much more faster than cakes. The waffles reached higher hardness and toughness values of the original values after 14 days of storage at room temperature inside MRE pouches with oxygen scavengers.

7. REFERENCES

AACC. 1983. Approved Methods of the American Association of Cereal Chemists, 8th ed. AACC. St. Paul, MN.

Alsberg CL. 1928. The role of starch in bread making. In: Walton RP, editor. A Comprehensive Survey of Starch Chemistry. Chemical Catalog Co., New York. P 87-99.

Axford DWE, Colwell KH. 1967. Thermal investigation of bread staling. Chem Ind London 467

Bechtel, W. G., and D.F. Meisner: Staling studies of bread made with flour fractions. IV. Effect of gluten and wheat starch. Cereal Chemistry, 31 (1954), 182–187.

Becker, A., Hill, S.E. and Mitchell, J.R. 2001. Relevance of amylose–lipid complexes to the behavior of thermally processed starches. Starch, 53: 121–130.

Biliaderis C.G., Page C.M. and Maurice T.J. (1986). On the multiple melting transitions of starch/monoglycerides systems. Food Chemistry, 22: 279–295.

Collar, C.,Martinez, JC and Rosell, JM (2001) Lipid Binding of Fresh and Stored Formulated Wheat Breads.Relationships with Dough and Bread Technological Performance. Food Sci Tech Int 7, 501-510.

Colwell KH, Axford DWE, Chamberlain N, Elton GAH. 1969. Effect of storage temperature on the ageing of concentrated wheat starch gels. J Sci Food Agric., 20:550.

D'Appolonia, BL (1972). Effect of bread ingredients on starch gelatinization properties as measured in the amylograph. Cereal Chemistry, 49:352.

Derby, RI, Miller, BS, Miller, BF and Trimbo, HB (1975) Visual observations of wheat starch gelatinization in limited water systems. Cereal Chemistry, 52:702.

Dragsdorf RD, Varriano-Marston E. 1980. Bread staling: X-ray diffraction studies on bread supplemented with α-amylases from different sources. Cereal Chemistry, 57:310.

Eliasson A.C. (1985). Starch gelatinization in the presence of emulsifiers. A morphological study of wheat starch. Starch, 37: 411–415.

Every, D., Gerrard, JA Margy, Gilpin,J., Ross, M. and Newberry,MP (1998) Staling in starch bread: the effect of gluten additions on specific loaf volume and firming rate. Starch, 50, 443-446.

Fennema, OR (1996) Food chemistry published by CRC Press, 773.

Gambus H. 2000. The role of starch in bakery products. Zywnosc 7(3):20 [Chem Abstr 134:130444 (2001)].

Ghiasi K, Hoseney RC, Zeleznak K, Rogers DE. 1984. Effect of waxy barley starch and reheating on firmness of bread crumb. Cereal Chemistry, 61:281.

Ghiasi K., Hoseney R.C. and Varriano-Marston E. (1982).Gelatinization of wheat starch. I. Excess-water systems. Cereal Chemistry, 59: 81–85.

Handleman, A.R., Conn, C.F. and Lyons, J.W. (1961). Bubble mechanics in thick foams and their effects on cake quality. Cereal Chemistry, 59, 500-506.

Hoseney C and Miller R. 1998. Current understanding of staling of bread. AIB Res Dept Tech. Bull. 20(6):1.

Katz JR. 1928. Gelatinization and retrogradation of starch in relation to the problem of bread staling. In: Walton RP, editor. Comprehensive Survey of Starch Chemistry. New York: Chemical Catalog Co. p 100-117

Kim SK and D'Appolonia BL. (1977) Bread staling studies. II. Effect of protein content and storage temperature on the role of starch. Cereal Chemistry, 54:216.

Kim, C.S. and Walker, C.E. (1992). Interactions between starches, sugars and emulsifiers in high ratio cake model systems. Cereal Chemistry, 69, 206-212.

Kim, S. K., and B. L. D'Appolonia: Bread staling studies. I. Effect of protein content on staling rate and bread crumb pasting properties. Cereal Chemistry, 54 (1977b), 207–215.

Kim, S. K., and B. L. D'Appolonia: The role of wheat flour constituents in bread staling. The Baker's Digest. 51 (1977a) 38–57.

Kim, S.S. and Setser, C.S. (1992). Wheat starch gelatinization in the presence of polydextrose or hydrolyzed barley β-glucan. Cereal Chemistry, 4, 447-451.

Knightly WH. 1977. The staling of bread: A review. Bakers Dig. 51(5):52.

Martin, M. L., K. J. Zeleznak, and R. C. Hoseney: A mechanism of bread firming. I. Role of starch swelling. Cereal Chemistry, 68 (1991), 498–503.

Megahey, EK, Mcminn, WAM. and Magee, TRA. 2005. Experimental study of microwave baking of Madeira cake batter. Food Bioproducts Processing 83: 277-287.

Mizukoshi, M. (1985). Model studies of cake baking. VI. Effect of cake ingredients and cake formula on shear modulus of cake. Cereal Chemistry, 62, 247-251.

Morgan KR, Gerrard J, Every D, Ross M, Gilpin M. 1997. Staling in starch breads. The effect of antistaling a-amylase. Starch/Stärke 49:54.

Painter, K.A. (1981). Functions and requirements of fats and emulsifiers in prepared cake mixes. J American Oil Chemists' Society, 58, 92-95.

Penfield, M.P. and Campbell, A.M. 1990h. Appendix D: Improvised Tests. In "Experimental Food Science," 3rd ed. pp. 519-23. Academic Press, Inc. San Diego, CA.

Pernell, CW, Luck, PJ, Allen Foegeding, E. and Daubert, CR. 2002. Heat-induced changes in angel food cakes containing egg-white protein or whey protein isolate. 67(8), 2945-2951.

Prentice, N., L.C. Cuendet, and W.F. Geddes: Studies on bread staling. V. Effect of flour fractions and various starches on the firming of bread crumb. Cereal Chemistry, 31 (1954), 188–205.

Rogers, DE, Zeleznak, KJ, Lai, CS and Hoseney RC (1988) Effect of natuve lipids, shortening and bread moisture on bread firming. Cereal Chemistry, 65, 598.

Sahi, S.S. and Alava, J.M. (2003). Functionality of emulsifiers in sponge cake production. J Sci Food Ag, 83, 1419-1429.

Spies, RD and Hoseney, RC (1982) Effect of sugars on starch gelatinization. Cereal Chemistry 59:128.

Sumnu, SG and Sahin, S (2008) Food engineering aspects of baking sweet goods. CRC Press

Szczesniak, A. S., Brandt, M. A., & Friedman, H. (1963). Development of standard rating scales for mechanical parameters of texture and correlation between objective and sensory methods of texture evaluation. Journal of Food Science, 28, 397- 403.

Vali, N.S.S.A. and Choudray, P.N. (1990). Quality characteristics of cakes prepared from different fats and oil. J Food Sci Tech-Mysore, 27, 400-401.

Varriano-Marston E, Ke V, Huang G, Ponte J Jr. 1980. Comparison of methods to determine starch gelatinization in bakery foods. Cereal Chemistry 57:242.